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JULY 1951

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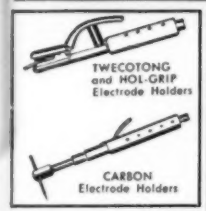

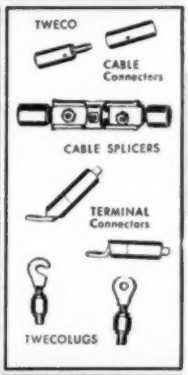

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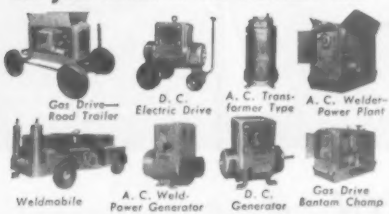

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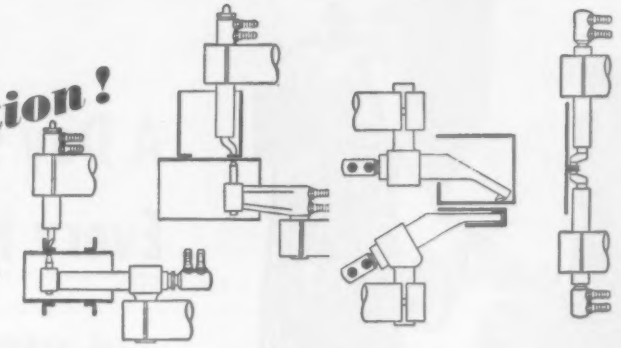

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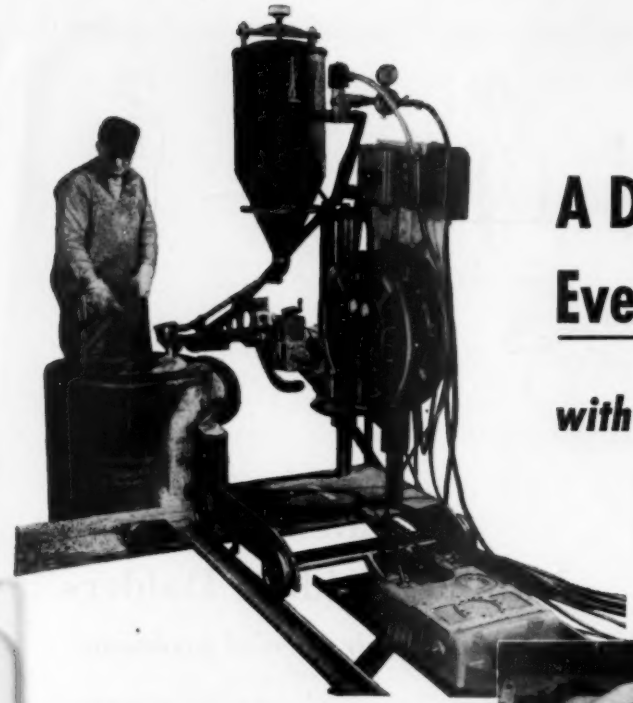

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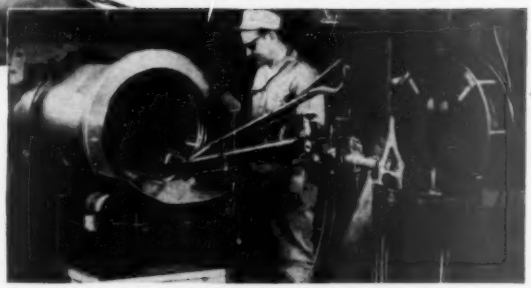

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The WELDING JOURNAL

Volume 30 **JULY 1951** *Number 7*

TECHNICAL PAPERS, ITEMS AND REPORTS

Design and Operation of High-Speed Production Tube Mills, by Donald H. Fleig 589

Current Welding Literature 596

Field Welding of Aluminum Tanks, by Perry C. Arnold 597

Should Welding Be on Its Own in Education? by Richard C. Wiley 602

Stress Concentration Problems in Welded Construction, by G. J. Green and D. H. Marlin ... 607

Correction 617

Sigma Welding of Nonferrous Metals and Alloy Steels, by H. T. Herbst 618

Quality Control of Structural Resistance Welding in Aircraft, by J. R. Fullerton 631

PRACTICAL WELDER AND DESIGNER

Design Data for Brazing—Part III. by W. J. Van Natten 634

Cutting Equipment Speeds Steel Mill Scrap Reduction 638

A Guide for Straight-Line Cutting, by H. P. Martin 639

SOCIETY AND RELATED EVENTS

Society News 640

Advertisers Index .. 643

Tentative Program Annual Meeting .. 648

Personnel 653

News of the Industry 654

Employment Service Bulletin 665

New Literature 668

New Products 669

Section Activities .. 672

List of New Members 675

Current Welding Patents 676

WELDING RESEARCH SUPPLEMENT

Interpretive Report on Box Girders and Small Specimens, by LaMotte Grover, E. M. MacCutcheon, W. S. Pellini, W. Spraragen and J. Vasta 321-s

Spot Welding of Scaly Heavy-Gage Structural Steel, by Ernest F. Nippes and John N. Ramsey 327-s

The New Bridge at Lanaye Over the Albert Canal, by R. Fougnies, H. Louis and P. Thys 336-s

Investigation of Submerged Automatic Welding, by L. N. Kushnarev 340-s

Welding Copper-Bearing Stainless Steel, by Helmut Thielsch 341-s

Welded Continuous Frames and Their Components, by Ching Huan Yang, Lynn S. Beedle and Bruce G. Johnston 348-s

Relative Strain Aging Tendency of Weld and Base Metal, Discussion by E. J. Ripling and L. J. Klingler 356-s

Connections for Welded Continuous Portal Frames by A. A. Topractsoglou, Lynn S. Beedle and Bruce G. Johnston 359-s

Pressure Vessel Heads Under Internal Pressure. 384-s

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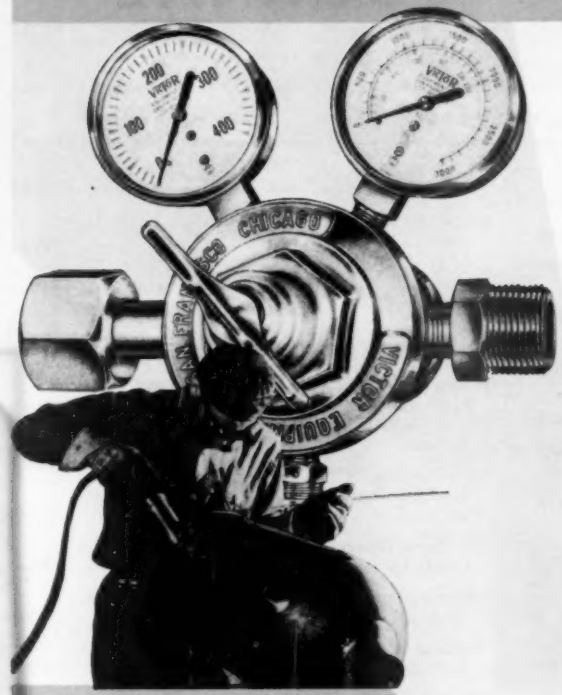

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The WELDING JOURNAL

volume 30 July 1951 number 7

Design and Operation of High-Speed Production Tube Mills

Various operations performed in a modern resistance welding tube mill are examined with a view to their coordinated functioning so as to bring about very high-speed production

by Donald H. Fleig

DUE to the demands of industry for more efficient production, practically all new welding equipment is being designed for operation at higher speeds. The production of resistance welded steel pipe and tubing has always been a relatively high-speed process due to its inherent easy adaptation to automatic operation. However, speeds from 30 to 70 ft. per minute are no longer considered sufficient, and the present trend is to speeds from 100 to 200 ft. per minute. These speeds require such precise and coordinated functioning of all the basic operations involved in producing commercial resistance welded pipe and tubing, that any small variation is greatly magnified. As a result, problems arise which are not encountered at lower speeds.

OPERATIONS OF A TUBE MILL

To better understand what these problems are and how they are solved, a description of the various operations performed in a modern resistance welding tube mill will be given. A complete tube mill, which will automatically produce finished tubing from coiled strip, has eight basic sections as follows:

1. Uncoiling reel.
2. Coil end joining equipment.
3. Tube-forming section.
4. Welding unit with its associated electrical control equipment.
5. Weld bead removing apparatus.
6. Straightening and sizing section.
7. Automatic cut-off equipment.
8. Tube removal and stacking equipment.

These eight sections are coordinated by both electrical and mechanical means so as to obtain the most accurate and yet the simplest possible arrangement.

UNCOILING REEL

The uncoiling reel can assume a variety of forms. The simplest is a bar supported in a suitable frame on which the coil of strip is supported through its center, and from which the strip is pulled by the powered rolls of the forming section.

Another more complex form is a motor-driven reel, which feeds the strip at a constant speed thereby relieving the main drive motor of this additional load. The reel motor has a variable output speed which may be either manually synchronized by means of a variable-speed transmission with the main motor speed, or form part of a direct-current variable-speed system which is automatically synchronized. To obtain the constant-speed feed, the coils are driven from their outside surfaces by two rollers which both support and rotate the coils.

At high speeds, it is essential to reduce down time of the mill to a minimum. The size of coil is usually limited to a maximum weight of about 800 lb., which for a 0.042-in. thick strip for a 1-in. O.D. tube gives a maximum coil length of about 1600 ft. At 100 fpm. this would last just about 16 min. and at 200 fpm., about 8 min. In order to maintain a continuous supply of strip into the forming section, the end of the coil must

Donald H. Fleig is connected with the American Electric Fusion Corp., Chicago, Ill.

This paper was presented before the Thirty-First Annual Meeting, American Welding Society, Chicago, Ill., week of Oct. 22, 1950.

be fastened by some means such as spot or flash-butt welding to the beginning of the next coil. This operation may take anywhere from 1 to 7 min. with the results that the down time may vary anywhere from 6 to 46%. To increase the efficiency, some method of looping the strip between the coil end-joining equipment and the forming section must be provided. With this looping equipment, the tube mill need not be stopped to join coil ends as the material in the loop will feed the forming section during this period.

JOINING EQUIPMENT

The joining of the coil ends may be done by either fusion or resistance welding. Coil ends of strip material under 0.072 in. thick may be joined by mash welding overlapped strip ends with a spot welder and hammering to flatten and reduce joint thickness. For greater thickness, flash welding or fusion welding must be used. Inert-gas arc welding of the butted ends without the addition of filler material and flux gives an efficient joint without bead. For locations where inert gas is available, this method would give the best joint for the least investment in equipment, particularly for heavy-gage material. Also it is readily adaptable to automatic operation. To obtain good joint fit, the ends of the coils may require shearing before joining by either the flash-butt or inert-gas arc methods.

The process which is most adaptable to automatic operation is flash-butt welding. An automatic flash-butt welder may be set for the particular size strip being welded, and will thereafter consistently produce good welds. After welding, the flash bead may be ground or machined off, but due to the limited time available at high strip speeds, the single-stroke drawcut machine is generally used as it is the most rapid. This is particularly true if the cutting is done immediately after flashing while the bead is still hot and relatively soft.

By the time this joint is complete, the strip contained in the loop has been depleted. Consequently, the reel speed must be increased until the loop is restored. To obtain automatic control of this, a two-speed motor should be used for the reel drive and suitable interlocking controls should be provided to operate the motor at the higher speed until the loop is restored, whereupon the slower synchronized speed would be restored. The operator would only need to stop and start the reel drive before and after each joint was made.

FORMING SECTION

The forming section consists of a series of pairs of rolls, which progressively form the flat strip into an open-seam tube ready for welding. Figure 1 shows the forming section of a typical tube mill. The diagram in Fig. 2, illustrates by cross sections the successive forming steps used in this tube mill. In this particular mill five steps are used for material up to 0.095 in. thick. For heavier wall thicknesses more steps are required. In forming at high speeds, there is apparently

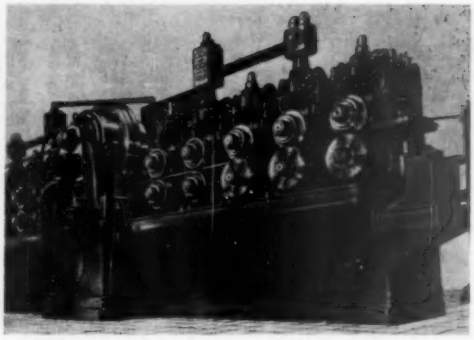

Fig. 1 Forming-roll section of a typical tube mill

Fig. 2 Cross section of strip in process of formation into a tube prior to welding for forming section of tube mill of fig. 1

no difficulty except if the forming rolls do not stay properly aligned, or the strip material has not had the two edges slit in the same direction. In either case the strip will creep out from between the pairs of rolls. At high-speed operation, this would occur so fast that the mill would become inoperable and might be damaged before the mill could be brought to a stop. To restrain sideways creepage of the strip vertical side-guide roll stands should be placed between adjacent horizontal forming roll stands, as shown in Fig. 3.

WELDING UNIT

The welding of the formed tube at high speeds introduces some interesting problems. The standard method of electric resistance welding consists in passing the

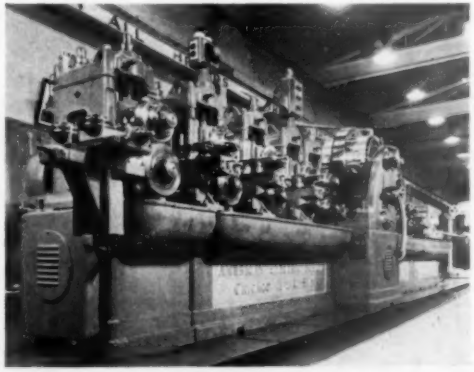

Fig. 3 Forming section showing side-guide rolls between adjacent horizontal forming rolls

Fig. 4 Welding transformer and pressure idler rolls

open seam of the formed tube under a pair of high conductivity rotary electrodes or welding rings, to which is fed a low-voltage, high-amperage current, and at the same time supporting and applying side pressure to the tube by a pair of idler rolls to butt weld the open seam edges together. The electrical power supplied to the welding electrodes may be either alternating current or direct current.

Alternating current is generally used because it is the simplest to convert from the standard high-voltage, low-current, alternating-current power generally available. The usual system consists of a regulating transformer, or other apparatus capable of producing a variable high voltage from the power line, and a welding transformer which converts the variable high-voltage, low-current power to a low-voltage, high-current power suitable for resistance welding. For maximum efficiency, this welding transformer generally is constructed so that it is mounted on the same shaft as the welding electrodes and rotates with them. The secondary is connected directly to the welding electrodes and the primary is fed through slip rings. In one design, the secondary is in the form of a copper drum on which are mounted the welding rings and in which the primary winding and core iron are totally enclosed. This is shown in Fig. 4. This has the advantage that very close coupling is achieved, and the length of the secondary circuit is reduced to a minimum with a resultant low-reactance and inherent high-power factor.

In the case of alternating current, the frequency of this current produces a stitching effect in the weld, the number of stitches per second being equal to twice the frequency in cycles per second. This stitching effect

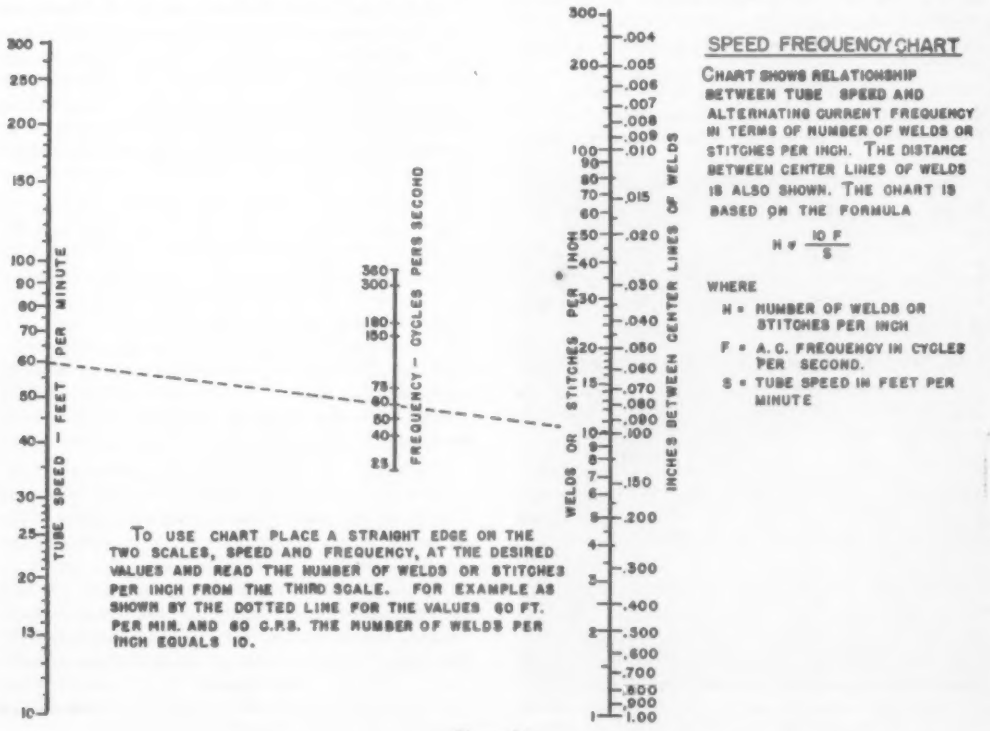

Figure 5

creates a problem in that for a given frequency, the number of stitches per inch of weld decreases as the speed of the tube increases. This is best shown by the formula

$$n = \frac{10F}{s}$$

where

n = number of stitches per inch.
F = frequency in cycles per second.
s = speed of tube in feet per minute.

A nomograph showing this relationship is given in Fig. 5.

The dotted line on the nomogram shows that for a given speed of 60 fpm. and a frequency of 60 cps., the number of stitches will be 10 per inch. For 16-gage, low-carbon, cold-rolled strip with this number of stitches per inch, the stitches will overlap producing a weld equal to or greater than the parent metal strength. However, at higher speeds, for instance 120 fpm. at which there will be 5 stitches per inch, they will not overlap. As a result, a definite observable stitching will be seen and the weld will be below the parent metal in strength. To overcome this difficulty when using alternating current, it is necessary to resort to a higher frequency such as 180 or 360 cps. With 180 cps. there will be 15 stitches per inch at 120 fpm. and with 360 cps., 30. Consequently, a frequency changer is required when operating at higher speeds. This has the advantage of changing the single-phase welding load, such as exists when operating on 60 cps., to a three-phase load.

This frequency changer may be of the induction frequency-converter type or the motor-generator type. The latter type is preferable, since with a single-phase welding load on the converter type, an unbalanced load is imposed on the three-phase supply lines. The motor-generator set is also more readily adaptable to stepless control of its output.

A variable voltage output is required to obtain the correct welding currents for the various sizes of tubing. If the frequency converter is employed, the output may be varied in three ways:

1. Tapped transformer regulator with fixed steps.
2. Induction regulator.
3. Electronic contactors with phase-shift heat control and electronic voltage regulator.

The first method is satisfactory for most low-carbon steels, and where the voltage supply to the regulator is constant. However, it has the disadvantage of having no automatic regulation if the voltage fluctuates and requires stopping the tube mill to change taps. The induction regulator overcomes the problem of changing the voltage under load, and when automatically controlled, can be made to correct for line-voltage fluctuations. However, it still has the disadvantage of requiring about one second to correct for line-voltage changes, and of adding unwanted reactance in the circuit. When operating at speeds of 100 to 200 fpm., if the line voltage dropped below the minimum required for welding, a one-second delay in correction would result in a poorly welded section of tubing from 1.5 to 3.5 ft. This might require scrapping a 10- or 20-ft. piece of tubing. The electronic contactor system possesses all the advantages of the voltage regulator plus the added one of correcting voltage fluctuation within 3 cycles of 60 cps., or $^1/_{20}$ sec. The only disadvantage of this is that the electronic contactor tubes must be de-rated for operation on 180 cycles and have a probable life of only one year. These would require replacement, whereas, no replacements would be required for the induction regulator.

In the case of the motor-generator set, the output voltage must be regulated by automatically controlling the field current because the inherent regulation of this type of generator is about 40%. To do this, the generator must be equipped with an automatic voltage regulator. Consequently, the method of using a tapped transformer to vary the voltage output could be readily used. The voltage regulation would be good but it would still not be possible to change taps under load.

The induction regulator could also be used in the motor-generator set, but since voltage regulation is already incorporated with the generator, the induction regulator need not be equipped with automatic voltage regulation control. The induction regulator, however, increases the kilovolt-ampere load on the generator because of the reactance it introduces into the circuit.

In the case of the electronic contactor it overcomes the disadvantages of the induction regulator and, as with the induction regulator, the automatic voltage regulator, which is included with the electronic contactor as a separate unit, can be omitted. Nevertheless, this electronic contact still has the disadvantage of requiring de-rating of the tubes and more frequent replacement of tubes when used at the higher frequencies.

As noted above, each of these methods possess a decided disadvantage. Now, due to the fact that the output of the synchronous generator can be controlled by regulating the field current, a complete electronic control can be obtained which incorporates a combination of voltage regulation and voltage control. This unit gives complete control of the voltage output under load and eliminates any additional reactance or costly replacements. The newest development in this type of control uses the magnetic amplifier which reduces maintenance and replacement costs to a minimum.

When used directly to weld tubing alternating current has one disadvantage which is difficult to overcome. This is the reactance of the welding transformer. The secondary circuit is the source of the majority of this reactance, which is greater the longer this circuit is. With the special design previously described in which the reactance is exceptionally low, the power factor of the total welding load on 60 cycles is exceptionally good. However, the power factor at 180 or 360 cps. is lower than at 60 cps. Consequently, higher speeds which require higher frequencies in order to obtain sound welds, result in lower power factor loads.

There are two solutions to this problem of decreased power factor. One is to install capacitors at the welding transformer to improve the power factor. A second solution is to use direct current. There are two possible sources of low-voltage, high-current direct current. One is a homopolar generator, and the other is a dry disk rectifier unit. With direct current there is no stitch effect and the only technical limitation on speed is the amount of power it is possible to convert with either of these two methods.

One of the most important factors affecting the welding of the tube is the adjustment of the pressure. As indicated before, the main portion of the pressure is supplied by a pair of idler rolls, as shown in Fig. 4. These rolls support the tube below the welding rings and apply side pressure to the tube at the same time welding current flows through the abutting edges, thereby producing a butt-welded joint. The effective pressure is not just the resultant of this side pressure, but also includes a vertical pressure from the welding rings. The effective pressure is not determined entirely by the physical relationship between the idler rolls and the welding rings but is influenced also by the initial size and shape of the tube and the gap width between the abutting edges before entering under the welding rings. These may be varied by controlling the forming done by the last roll stand in the forming section of the tube mill.

It is interesting to note that when the pressure is once determined for a given speed, the speed generally may be increased without altering the pressure.

On the other hand the electrical power increases with increase in speed. The increase in power is not proportional as the amount of increase becomes less as the speed increases. This is best demonstrated by Fig. 6 which shows the relationship between power in kilowatts and speed in feet per minute for a given wall thickness and diameter of tube. This can be readily accounted for by the fact that as the speed increases, the thermal losses decrease because there is less time for the heat to dissipate at the instant of welding.

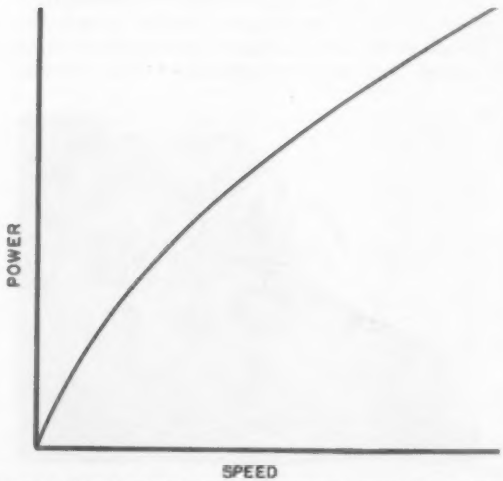

Fig. 6 Relationship between power and speed for a given wall thickness and tube diameter

FINISHING OPERATION

The step following the welding of the tube is that of removing the weld beads. The tube has an internal and an external bead. The external bead is relatively easy to remove as it can be scarfed with a metal-cutting high-speed steel or carboloy tool bit immediately after the tube is welded and while the bead is still hot. This is shown in Fig. 7. To remove the internal bead is a much more difficult problem, and becomes even more so as the speed is increased. The difficulty also increases as the diameter of the tube decreases. One successful method of removing both beads simultaneously is to use an air hammer and a floating internal mandrel. If the tube is of large enough diameter, it is possible after scarfing the external bead to roll the internal bead. The maintenance of internal bead removing equipment increases as the speed increases.

The next step in this process is the sizing and straightening section, as shown in Fig. 8. In this the tube is rolled down to final size and straightened. It is extremely important that an accurate and easily adjustable means be provided for straightening when operating at high speeds. The straightness of the tube influences efficiency of operation of the cutoff and the automatic handling-and-stacking equipment.

Fig. 7 External bead scarfing assembly

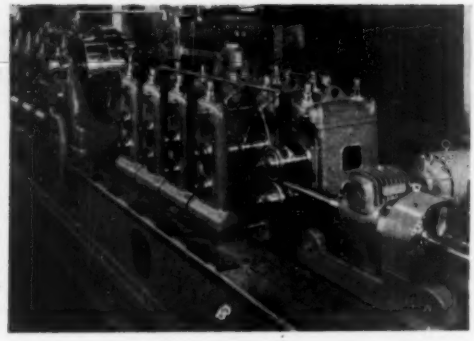

Fig. 8 Sizing and straightening section of tube mill

CUTOFF EQUIPMENT

The cutoff equipment is a very important section of the tube mill. When tubing is leaving the sizing and strengthening section at from 100 to 200 fpm., the cutoff equipment must be an extremely sturdy and reliable mechanism. The cutoff device must cut the tube while it is moving. To do this a suitable clamping means is provided which clamps the tube and causes the cutoff equipment to move at the same speed as the tube. During this time, some type of metal-cutting device cuts the tube to a predetermined length. When the cut is finished, the cutoff clamp releases the tube and the whole cutoff equipment automatically is returned to its starting position. To perform this operation accurately at high speeds requires a very precisely operating mechanism.

For instance, if one desired to cut 20-ft. lengths of tube with the tube traveling at 200 fpm., it would require 10 of the previously described operations per minute. This means that the cutoff equipment must make one cut every 6 sec. It must start from standstill, clamp the tube and reach the tube's speeds, cut off the tube and return to its original position in 6 sec. For a speed of 100 fpm., the total time per piece would be 12 sec., but if the piece lengths were reduced to 10 ft., the time would again be only 6 sec. Consequently, as the speed is increased, the minimum length that can be successfully cut increases.

One method of cutting off is to mount the clamping and cutoff tools on a carriage which rolls on a track. This is coordinated electrically so that when the tube strikes a length-gage switch, the clamp is energized and clamps the tube. At the same time, a locating latch which locks the carriage in the same starting position is released. The weight of the carriage must be reduced to a minimum so that the starting inertia is as small as possible. The forward movement of the carriage moves a cam lever which causes the cutoff tool to cut the tube. Upon completion of the cut, a limit switch is actuated by the carriage and, as a result, the clamp is released. The carriage is immediately returned to its starting position by a spring and/or counterweight, or by a hydraulic or pneumatic cylinder. An example of this is shown in Fig. 9.

There are four possible methods of cutting off the tube. These are

1. Rotating lathe tools.
2. Rotating roller pipe cutters.
3. Friction saw.
4. Punch cutter.

The rotating lathe tools give the cut with the least burrs or other marks. What burr there is, is on the inside. The rotating roller pipe cutters give a clean cut, but roll the ends of the tube inward. The friction saw leaves a burr on both the inside and outside. The punch cutter with a single-action die makes a clean cut but leaves an indentation on the tube end. It is possible to eliminate the indentation by using a double-action die, but this greatly increases die maintenance.

As to cutting speed, the punch-type cutter is the fastest, but it is limited to 2-in. maximum tube diameter. The friction saw is the next in speed. The slowest are the lathe tools and the roller pipe cutters, which have about the same speed. The roller pipe cutters are limited as to the wall thickness that they can cut.

When operating at high speeds, the length of tube, as shown previously, governs the amount of time available for cutting-off. Also, the desired end finish of the tube will determine the type of cutoff tools to be used. This will in turn dictate the minimum time that is required to make a cut. If the length of tube is such that the available time at a given speed is less than the minimum cutting time required, then a compromise must be made. Oftentimes, it is more economical to cut multiples of the desired length and then cut the final lengths on some other type of machine.

If a given length can be cut in the time available, the accuracy of the cut length is the next consideration. The difficulty of maintaining a required accuracy increases as the speed increases. Such factors as clamp slippage, consistency of actuation of the clamping

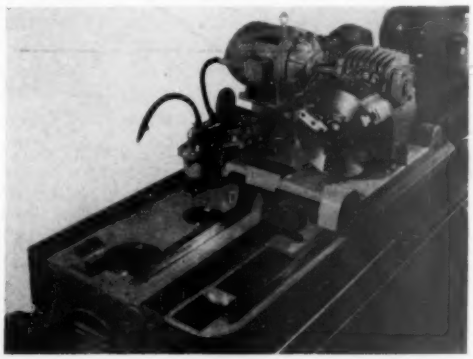

Fig. 9 Typical cutoff carriage showing rotary lathe type and tracks

means, and accuracy of the electrical components governing the cutting-off must be considered. For instance, if the clamp is powered with a pneumatic cylinder, variation in air pressure will affect the speed of clamping. If the air cylinder is controlled by means of an electric solenoid valve, and this solenoid is controlled from an alternating-current circuit, the variation in operation of the solenoid valve will be $\pm 1/120$ sec. Such a variation at 100 fpm. will mean possible variation in tube length of $\pm 1/8$ in. This will not be satisfactory as $\pm 1/8$ in. is about the maximum allowable. Consequently, to obtain more consistent operation a direct-current solenoid must be used. Variation in air pressure could be eliminated by using a reservoir air tank adjacent to the air cylinder to minimize the effect of air pressure variations or by using a clamp directly actuated by a direct-current solenoid.

Variation due to clamp slippage is a difficult problem because of the uncertain condition of the tube surface. One method of eliminating this is to use a positive stop, permanently secured to the cutoff carriage, instead of a momentary contact switch to actuate the clamping. This positive stop would serve two functions. One is that it would start the cutoff carriage moving before the clamping took place, thereby eliminating slippage. The second is that it would definitely establish the cutoff length before the clamping took place and would be independent of clamping. However, such an arrangement requires a long extension to support the permanent stop, which will greatly increase the weight of the carriage, and thereby place a heavier load on the tube which must move the carriage. Another disadvantage is that thin-wall tubing may not have sufficient rigidity to start the cutoff carriage moving without bending. The third disadvantage is that in order to remove the piece of tube after cutting, a complicated device must be employed to swivel the permanent stop out of the way.

One way to combat clamp slippage is to give the cutoff carriage a push by means of a hydraulic or pneumatic cylinder just prior to clamping so that the inertia of the carriage is reduced. The force required to bring the carriage up to the speed of the tube varies directly as the difference of the squares of the velocities of the tube and carriage. That is

$$F = \frac{m_c(v_t^2 - v_c^2)}{2S}$$

where

F = required force, lb.
m_c = carriage mass, W_c/g, where g = acceleration of gravity = 33.2 ft. per sec. per sec.
W_c = carriage, weight, lb.
v_t = tube velocity, fpm.
v_c = initial carriage velocity, fpm.
S = distance in feet in which the acceleration of the carriage from v_c to v_t takes place

To prevent marring of the tube surface, the clamping jaws must be smooth. Consequently the force F is developed entirely by friction between the tube surface and the clamping jaws and is given by the following formula:

$$F = uN$$

where

u = coefficient of friction.
N = normal force or clamping force.

Due to variable surface condition of the tube, u, the coefficient of friction, is a very uncertain factor. Therefore, the total clamping force, N is given by:

$$N = \frac{m_c(v_t^2 - v_c^2)}{2uS}$$

From this it is evident that the smaller the factor $(v_t^2 - v_c^2)$ the smaller will be the required clamping force and the more independent it will be of the variable coefficient of friction. Also the smaller the mass of the carriage, the smaller will be the required clamping force.

The momentary contact switch may be of two types. The first is a flag switch, which is struck by the end of the tube. The other is an electric eye, in which the end of the tube interrupts a light beam, which keeps the eye energized. For the greatest accuracy of operation they should be mounted on an extension of the cutoff carriage. This extension requires a second support and adds weight to the carriage. If a carriage latching device is used to establish a definite starting point, both types may be mounted on an independent stand, thereby not increasing the cutoff carriage weight.

TUBE REMOVAL AND STACKING

The cutoff tube is received by a suitable tube-handling device, which may stack it or feed it to an end-trimming machine where required. As indicated before, the production of 20-ft. lengths at 200 fpm. will require the handling of 10 pieces per minute or one piece every 6 sec. Consequently, the handling equipment must be considered when deciding the minimum length of tube to be cut.

An important consideration in the operation of the tube mill at high speeds is the condition of the material used. As indicated previously, increase in speed magnifies every small variable. The strip material used must have the edges accurately sheared in the same direction. The strip surface must be clean to provide good electrical contact and to insure the production of tubing without excessive marks. Cold-rolled material is practically mandatory except in the cases where hot-rolled stock is given a special pickling, cold-rolling and shearing treatment.

In an article on "Electrical Resistance Welded Steel Tubing" in the *Iron and Steel Engineer* of August 1947, Allardt gives an excellent description of a special treatment applied to hot-rolled mill-edge strip employed in the production of tubing at speeds between 100 and 200 fpm. He contends that this special treatment is absolutely essential at high speeds as it is difficult enough to produce tube from strip of variable chemical content over which they have no control without permitting other variables to exist which they can control. With the use of cold-rolled material this special treatment has

been found to be unnecessary since by accurately maintaining the width and thickness of the cold-rolled material excellent results have been obtained at a speed of 175 fpm.

In general it has been found necessary to restrict the grade of material to under 0.15% carbon. Usually S.A.E. 1010 or S.A.E. 1015 steels are found to be most satisfactory with a Rockwell B-scale Hardness between 50 to 70.

The accurate control of speed is essential for consistent production of resistance-welded steel tubing at high speeds. Three methods of speed control are available.

One uses a constant-speed motor with a mechanical reduction and speed change using either sprocket gears and chain or sheaves and V-belts. Usually an alternating-current squirrel-cage induction motor is used because the load is practically constant for any given speed and tube size. Speed changes are obtained by means of a series of different size sprockets or sheaves. This system is very stable and requires a minimum of maintenance.

A second system uses a constant speed motor with a variable speed transmission and speed reducer. With this system the speed may be adjusted while operating. It usually consists of a double adjustable pulley combination to form a V-belt drive. It is a convenient system for changing speeds, and speed ratios up to 16 to 1 are available. Operating efficiencies depend on a large number of variables and can be expected to be about the same as those of a V-belt drive operating under extreme conditions.

The third system uses a variable-speed direct-current motor whose speed is controlled through an adjustable direct-current voltage to the motor armature and through an adjustable field control. Two sources of power are employed. One is a completely electronic system which operates from the three-phase alternating-current line. The other is a motor-generator set operating from the alternating-current line and supplying the direct-current voltage for the direct-current drive motor. This may have either standard rheostat control or the more versatile electronic control. This third system using a variable-speed direct-current motor is the most flexible as speed ranges of 40 to 1 or greater may be obtained. It is, however, more complex and requires expert maintenance.

In this paper, we have endeavored to show all the problems that may be encountered in high-speed production of resistance welded tubing, and how they may be overcome. In all cases, it is usually possible to do this if no consideration is given to the initial cost. However, due consideration must be given to the economical production and certain compromises will be necessary. Maintenance is also of great importance, and will influence the ultimate selection of the refinements used. However, it will be found that if all these factors are properly selected to give the desired product, resistance welded tubing and pipe can be produced very economically at high speeds.

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(*Continued on page 617*)

Field Welding of Aluminum Tanks

Story of how several large aluminum storage vessels were erected including welding sequence to avoid distortion and warpage

by Perry C. Arnold

ONLY a few years ago, the fabrication of an aluminum storage vessel by welding was considered a sizable task. Today, fabricators are supplying aluminum storage and pressure vessels, of welded construction, in great numbers. The atomic age accounts, in part, for the increasing demand for such vessels. Products such as concentrated nitric and acetic acids, hot ammonium nitrate and liquid oxygen or nitrogen are very successfully stored in aluminum vessels. The advent of the inert-gas-shielded arc method of welding aluminum and its alloys has greatly increased the production of these vessels. This method made it possible to secure the necessary strong, very ductile high quality weldments that make quantity production possible.

The primary purpose of this paper is to bring to you, through description and pictures, the story of how several large aluminum storage vessels were erected and welded. Welding data, procedures and tables are not given in this paper as they have been well presented in previously written articles by the material and equipment manufacturers. Your attention, however, is especially called to the rather unique method used to erect the vessels. This erection and welding sequence was developed by the Chicago Bridge & Iron Co.

Figure 1 shows a 35-ft. diameter by 28-ft. high storage tank, of 200,000 gal. capacity, that was erected to store hot ammonium nitrate. The material used was 3S aluminum. The first ring of this vessel was 1.03 in. in thickness. The other rings gaged 0.78, 0.52 and 0.27 in. in thickness. The center portion of the bottom was $^3/_{16}$ in., 3S material and the sketch plates were made of $^1/_4$-in. thick plates. The roof is an umbrella or self-supporting type made of $^3/_{16}$-in. thickness mild steel. In order to prevent corrosion from occurring at the junction of the steel roof and the aluminum top angle, the two were separated by a rubber gasket and held together with galvanized steel bolts and washers.

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This paper was presented before the Ohio State Welding Engineering Conference on Apr. 13, 1951.

Figure 1

Figure 2 shows the beginning of construction. First, a temporary steel angle was assembled around the periphery of the foundation. The mild steel roof plates were then blocked up and fitted to this angle. Figure 3 shows more in detail how the roof plates were fitted together and to the temporary angle. The temporary angle was used in order to assure a good fit when the mild steel roof was fitted to the aluminum top angle of

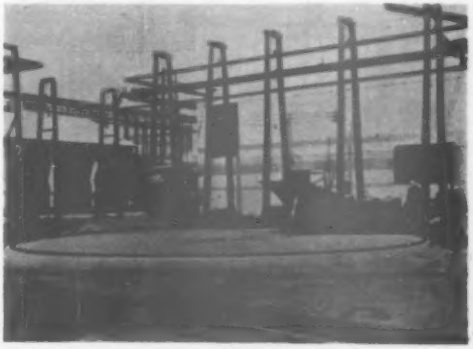

Figure 2

the tank. Please note that the roof of this tank is being erected and welded together prior to the erection of the aluminum tank proper.

Figure 4 shows that at the same time the roof was being erected, the aluminum bottom and first ring of the tank was being erected at a location adjacent to the foundation. This speeds up production by allowing the workmen to spread out and work on more than one portion of the tank at the same time. Note that both the roof and the aluminum ring is being fitted together using patented key equipment.

Figure 5 gives a little closer view of the first ring and the bottom-plates being assembled.

After the mild steel roof was completely assembled and welded, it was raised high enough to allow the top ring of the tank to be assembled on the foundation directly beneath the roof. As soon as the top ring was assembled, welded and bolted to the roof plates, the entire assembly was then lifted and another ring assembled directly beneath it. Figure 6 shows how the next to the top ring was assembled beneath the top ring and roof assembly. This scheme of erection and welding made it possible to do all of the erection and welding near the ground. Only a very small amount of scaffolding was thus required.

Figure 7 shows the top two rings and roof being raised and held high while the second ring was erected. As soon as the second ring was completely assembled, the upper assembly was lowered and allowed to rest on the second ring.

Figure 3

Figure 4

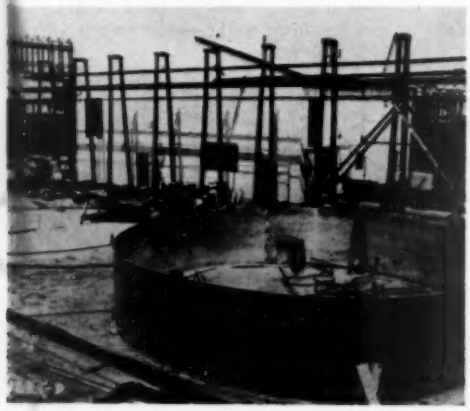

Figure 5

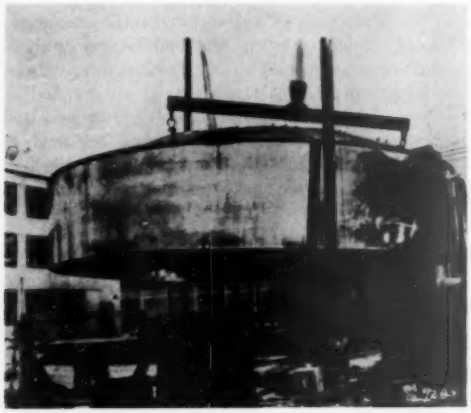

Figure 6

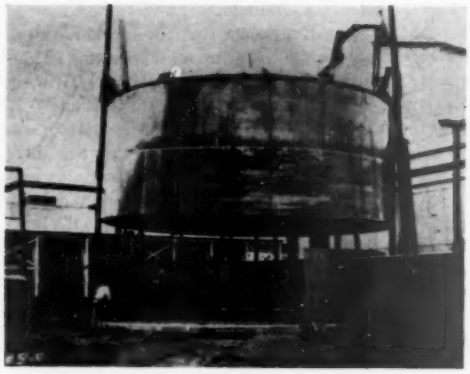

Figure 7

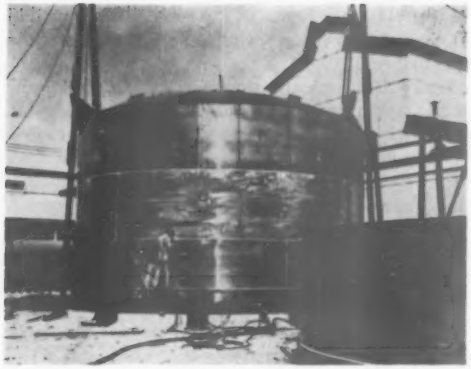

Figure 8

Figure 8 shows a welder at work on the joint between the second and third ring. Note that the first ring and bottom have been assembled and welded and are now ready for sliding under the large assembled portion of the tank.

Figure 9 shows the bottom and first ring assembly being pulled under the assembly of the rest of the tank. Rollers were used to facilitate moving the first ring assembly onto the foundation.

Figure 10 shows the completed tank. All of the fittings and nozzles were field installed. The inert-gas-shielded arc method of welding was used. A standard make transformer provided the welding current. A current of high frequency was superimposed upon the welding current to facilitate striking the arc. Tungsten electrodes, $^3/_{16}$ and $^1/_4$ in. in diameter, were used in an atmosphere of argon gas. The aluminum plating of $^3/_4$ in. thickness and over was preheated to about 600° F. to facilitate and speed up the welding. The connection of the first ring to the bottom was a standard T-joint as is customarily used in mild steel tank construc-

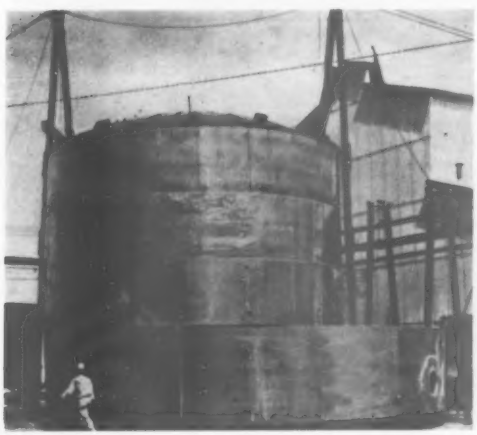

Figure 9

Figure 10

tion. Trepanned specimens were taken from the welded joints as per A.P.I. requirements. The specimens proved the weldments to be free of cracks and other defects. The primary stressed joints were back-chipped to sound weld metal to doubly insure full fusion and penetration. All of the joints in the shell proper were made of butt-type construction, while the bottom was made using lapped-type joints. Type 2S bare aluminum electrodes of $^3/_{16}$ and $^1/_4$ in. diam. were used.

Only a few years ago this tank would have been welded using the oxy-acetylene or oxy-hydrogen method. Much greater warpage and distortion would have occurred. Due to the distortion factor, it would not have been possible to use the T-type joint at the junction of the bottom and the first ring. The lap-welded bottom could not have been used due to the corrosion that would have occurred between the joints from the electrode flux which would have been deposited there. The inert gas-shielded arc method of welding has contributed much to the art of joining aluminum plates.

Today a variation of the inert gas-shielded arc method is coming rapidly to the front. This latest method utilizes a consumable electrode fed at a constant rate into the inert arc atmosphere. Much greater speed of welding is made possible with less distortion and warping. However, so far the quality of the weldments has not been as good as when the tungsten arc is used. This discouraging factor will soon be overcome as more use is made of the new method.

Figure 11 shows the very beginning of erection of six 17-ft. diameter by 18-ft. high aluminum tanks for the storage of acetic acid. Each tank has a capacity of 30,000 gal. The material used was 3S aluminum joined together by the inert-gas-shielded arc method of welding. Again, type 2S aluminum bare electrodes were used. The bottom was made of $^5/_{16}$-in. thick plates with the outer edge turned up to meet the first ring of the shell. The shell of the tank was made of

$^5/_{16}$- and $^1/_4$-in. thick plates. The roof was also made of $^1/_4$-in. thick aluminum and of the self-supporting type. These tanks were designed to use the butt-joint type of construction throughout.

Figure 12 shows a welder at work on the first ring plate to the bottom joint. The torch used was of the water-cooled type and due to winter conditions an anti-freeze compound had to be added to the water supply.

Figure 13 shows a welder making the joint between the roof and the shell. Again the method of erecting the tanks from the roof down was used rather than the conventional method of erecting the tanks from the bottom up.

Figure 14 shows how steel strong-backs were used at the tops of the vertical seams to keep the tanks round and true.

Figure 15 shows the top rings of the tank being erected on the foundations and the roof attached.

Figure 16 shows several of the tanks being erected simultaneously. Note that the bottoms and first rings are being erected and welded adjacent to the foundation at the same time the top rings and roofs are being erected.

Figure 17 shows the many nozzles and manways that had to be field installed and welded. Also note the smooth contour taken by the roof plates.

Figure 18 shows a truck crane lifting the roof and top

Figure 11

Figure 12

Figure 13

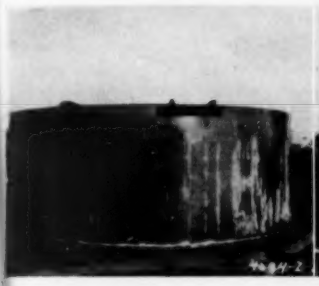

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Figure 19

ring assembly piece so that another ring can be erected on the foundation. The section was lifted directly from the center of the roof and balanced by a secondary set of rope falls. The large number of fittings located on one side of the tank unbalanced the load.

Figure 19 shows the tanks completely assembled. The weld between the first and second ring is yet to be made. Note that patented key equipment is used to hold the girth seam in alignment.

Figure 20 shows the six tanks practically completed.

Figure 21 shows the tanks after completion and the area cleaned up and graded. The tanks all successfully passed a water test prior to going into service. The weldments in the roof, shell and bottoms were all sampled by the trepanning method to prove the quality of the welds.

Figure 22 shows a 12-ft. diameter by 50-ft. long horizontal tank that was fabricated of 3S aluminum material of $^3/_8$ in. thickness. This tank was completely fabricated in the shop and shipped out in one piece. The inert gas-shielded arc method was used to make the weldments. Material stored in this vessel had a specific gravity of 1.38. It was, therefore, necessary to stiffen the shell of the vessel with large internal girders.

Several aluminum storage vessels have been erected in the past using the metallic arc-coated electrode method of welding. The weldments produced by this method have given good strength, but very poor ductility. Also, the flux from the electrode had to be thoroughly washed from the material to avoid corrosion.

So far the paper has described the welding of the non-heat treatable alloys. The heat treatable alloys are now being welded with moderate to good success. We very recently erected and welded an aluminum floating roof for one of our customers. 61ST material was used throughout. The thicknesses ranged from $^3/_{32}$ to $^3/_8$ in. The welding was completed using the inert gas-shielded arc method. Alternating current with high frequency was used with an atmosphere of argon gas. Welding electrodes were bare and type 43S aluminum.

It is true that welding heat-treatable aluminum alloys destroys some of the strength that is provided by the heat treatment. However, experience has shown that the heat-affected zone will have a strength somewhat higher than the dead soft material and somewhat less than the heat-treated material. In other words, not all of the higher strength of the heat-treated alloy is lost due to the welding operation.

In our experimental work with the inert gas-metallic arc method of welding aluminum we have found that weldments can be made on the high strength heat treatable alloys such as 52S without too much difficulty. This was considered practically an impossibility with the old oxy-hydrogen or oxy-acetylene process.

In the last few years great strides have been made in the fabrication and welding of aluminum and its alloys. As greater need arises for more aluminum vessels, more progress will be made. Even now fabricators and welding equipment manufacturers are finding that a mixture of inert gases is beneficial to some types of

Figure 20

Figure 21

Figure 22

weldments. They are also close to eliminating the porosity problem which has long been with us. Super cleaning of the plates and the electrodes helps the porosity problem. Preheat is often beneficial not only for obtaining higher quality welds, but for speeding up welding.

There are many inherent factors associated with aluminum and its alloys that must be recognized by a fabricator or manufacturer, if he is going to do the job well and efficiently. Aluminum has a coefficient of expansion of approximately twice that of iron. Thus, its greater distortion and warpage. The thermal conductivity of aluminum is many times greater than that of iron. Thus, more heat input is required, thus more expansion, thus more warpage and trouble. A heavy skin type of aluminum oxide forms over a welding puddle. The melting temperature of this oxide is several degrees higher than that of the parent material. Thus the oxide must be eliminated, fluxed out or kept from forming. Some of the alloys added to aluminum cause the material to become hot short, which tends to cause cracks as the material cools down from welding temperatures.

In spite of these inherent difficulties, great progress has been made in the welding of aluminum. More progress has been made in the last five years than was made in the previous twenty. The present-day conditions or the atomic age is going to force other rapid advancements in the use and fabrication of aluminum. Who knows, even tomorrow may bring about the introduction of a new welding process for aluminum.

Should Welding Be on Its Own in Education?

Colleges can do much to help the welding industry by determining its needs in the matter of training and supply such needs in so far as they lie within its scope of training in the fundamentals of engineering

by Richard C. Wiley

INTRODUCTION

THE use of the various welding processes in the metal-working industries, and hence in all of our industrial productive society, has become universal in its acceptance. However, in this acceptance there is one outstanding discord, which many men within the industry feel should have careful consideration if welding is to continue and to grow. This unfilled need is that of supplying industry with trained welding technicians.

Education has an important part in furthering production. It is doing a good job, but possibly some strengthening is needed in certain areas. In most cases, colleges apparently are not aware of the potential of the welding field. Yet, industry has to be aware of its importance! However, it should not be the entire province of industry to supply its own technicians. Few other fields stand so isolated as does welding in calling upon education to supply its needs.

An example of this lack is found in the policy of a leading manufacturer and distributor of welding supplies and equipment who finds it necessary to teach recent graduate engineers just employed the fundamentals of welding. Another example is that of a large aircraft manufacturer who sends his design and process engineers to a night-school vocational welding program. It would be unthinkable to have to farm out such men to gain their calculus or strength of materials. And yet this is the situation in welding education today. Industry recognizes the need engineers have for the basic welding techniques and processes. The engineer does not need to be a welding operator to be sure, but to do a better job in his everyday design problems in metal fabrication this knowledge should be a part of his regular engineering course.

Dealing with the over-all problem of engineering education, there are some colleges in which the belief is that no specialization or deviation from fundamentals should take place during the undergraduate years. It would seem that the result of this viewpoint would produce unhappy graduates as well as employers. In considering the average engineering student, and not the man who will do graduate work and research, this average man would be tossed out to industry to be trained for a specialized area, which would be unnecessarily costly in time and money both to industry and to the man himself.

Other colleges have viewed the general problem from a different light. In several western colleges there is a great stress of fundamental subjects along with some specialization option during the senior year. This plan would seem to be a more realistic approach, and one more profitable to the engineer, to industry and to education.

Welding is one of the possible college engineering specializations, but it is probably one of the weakest in spite of the strong position of welding in industry today.

As welding exists now in college engineering education it is hardly more than in its infancy. Perhaps it seems too early to be bothered with inquiring, "Should Welding Be on Its Own in Education?"—but the opportunities for future development are with us now. The questions which face us are: What can education do? What can industry do?

RECENCY OF WELDING

Certainly up to within twenty years ago, we all know that welding was mainly used as a means of making repairs. A technological growth has made possible its widening use as a means of fabrication. However, there has not been a parallel growth in providing technically trained men for its efficient operation. The gap between the operator and the design engineer has increased. As the processes grow and become more complex, where is industry to find the required personnel to carry on its operations and developments? Many of these men were once brought up from the operator level. Those were the days when a welding operator was given the blueprints and carried through the job from start to finish. He was a skilled craftsman. We still have some today. No reflection is meant to any of our present welding operators, but

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their concern is now largely one of making a good weld only. A relatively few men from the mechanical, electrical or metallurgical engineering fields have gradually begun to enter into an active part in solving some of the problems presented. As the industry has become broader and more complicated it is even more important to have technically trained men in responsible positions. The operator level can no longer serve as the main reservoir. Yet young men from engineering colleges do not have sufficient background in welding. This is about the picture at the present time.

Either industry will have to assume the ever-increasing burden of training men for welding activities, or colleges must be encouraged to provide at least some formal training for them. Mere shop-type activity will not answer the purpose. Neither will a theoretical course in advanced physical metallurgy. Each may have its particular part but what is most needed is something which should extend beyond basic fundamentals in science, mathematics and pure engineering into the application of these fundamentals in industrial problems of design, construction of equipment and structures. As it can readily be seen today, the need for trained men will continue to increase because of increasing technical developments that are now being used as well as those that will be developed in the years to come—thereby increasing the need for men specially trained for this field. It is indisputable that welding has come far, but it is open to conjecture as to how far it can go with a body of men specifically trained and concerned with its various aspects.

WELDING IN COLLEGES AND UNIVERSITIES TODAY

From the preceding discussion, the need for advanced training is apparent. The next consideration is how well, if at all, is this need being filled by educational institutions? An investigation of the courses dealing with welding offered in 12 western colleges and universities reveals, in general, a bleak picture. In the main, these courses are tied in with one or more related metal-working subjects. In one instance a university achieves the acme in tie-ins by combining the study of machine tools, arc and oxyacetylene welding, foundry, electric wiring and molding of plastics all rolled together in a one-unit shop course! The most common packaged course in universities is in forging and welding given for one unit, generally, and two units at the most. One university includes one two-unit course in welding metallurgy.

As to the colleges, mainly the state colleges, again is found the package deal ranging from forging and welding to ornamental iron work. One southwestern college has a two-year terminal course apparently designed for welding operators, but one which would give a man a good foundation to continue progressing in the welding field. In another western college there are individual courses in oxyacetylene, arc, special processes and elements of welding design. Thus, in all but two out of twelve western universities and colleges there is scarcely enough welding even to awaken a spark of interest or enthusiasm in the average engineering student. It is a wonder that welding has come as far as it has considering that at one end the old engineer is suspicious of it and at the other end the young engineer is unprepared for it.

There are many reasons for the existing slowness in education. Some of these reasons are understandable, but hardly any of them seem justifiable. Examining but a few, first, there is the ghost called "lag" between need and actuality which runs across the whole field of education. Second, old-line engineering groups in education are reluctant to give up some of the students and some of their prestige to newer fields. Third, there are not enough properly trained instructors who wish to enter the presented limited field; industry can and does offer them more opportunity. Fourth, administrators, other engineers, instructors, as well as students, and the general public have a rather low regard of welding. This attitude might be traceable to the caliber of the local garage and repair men who do "welding." Also, the speed-up training of welding operators during World War II has made the public believe that there is not much to learn. Even Winnie-the-Welder could do it! Fifth, the effort to crank up a new program is usually overcome by inertia, that is, the desire to go in the same path. Budgetary expenditures and floor space are carefully guarded by existing college departments, thus making movement difficult if not impossible.

Seemingly, as far as most college laboratory courses in welding care to go is simply to have the student as an observer and demonstrate the welding processes. In other words, it is a spectator sport! The lack of understanding as to the scope and application of welding is perhaps the greatest single drawback with which we must deal in furthering welding education. Industry has managed to overcome this difficulty to a great extent in its own immediate area, but more spadework in public relations, imparting information or plain "selling" is needed in the educational field. Who should do it and even how to do it are open questions, but if welding has value, then for the ultimate good of society (man in his upward struggle) it must be done.

PRESENT NEED IN INDUSTRY FOR MEN TRAINED IN WELDING

Let us attempt to identify some objectives. Men are needed for research; more men are needed for production. It is not within the scope of this paper to discuss the requirements and qualifications of men going into the advanced study of welding. That could be another paper in itself. Our concern is that of welding technicians who will enter design, production or sales

here on the West Coast. In investigating this particular aspect of the problem, there is definite indication of a need and a willingness on the part of industry to accept graduates who are well grounded in the fundamentals of welding engineering in preference to those with a mechanical or other engineering background.

In order to determine what such a student should receive in the way of training, it is necessary to look into industry to see what is required. Granting the essential engineering fundamentals, let us proceed to the specific work of the welding technician in production as an example. The work in design or sales falls into this pattern with some modifications. Brooking in his book, *Arc Welding Engineering and Production Control*, states: ". . . general operations and problems of organization that must be dealt with in arc-welded production.

1. Evaluate and select welding processes, machines and equipment.
2. Evaluate and select appropriate welding electrodes for all processing done in the plant.
3. Examine and evaluate welding operators seeking employment.
4. Train and adapt welding operators to the company's special processes.
5. Correlate welding design with practical shop practice and available shop equipment.
6. Create production fixtures for welding (setting up and positioning for welding).
7. Establish the general procedures for welding the company's products.
8. Establish production control of procedures in detail.
9. Establish quality control (inspection).
10. Keep informed on practices and processes in the industry so as to keep the company's processing up to date."

Before progressing further, it might be noted that this book is one of the very few which thoroughly covers welding-production operations on a mass-production basis.

The ten points which Brooking brings out are not necessarily the answer in every case. However, most plants using welding extensively as a fabrication method would find that these would fit their operations to a considerable extent.

In view of such requirements within the industry, it would be well if engineering education could make available to the young man of a mechanical-engineering background in a senior year option-course in welding technology the familiarization of the principal welding and cutting processes. These should include design of welded pressure vessels according to the various codes, cost estimating for all types of weldments, methods of redesigning castings, design of products for resistance welding, welding metallurgy, production control, quality control and time study.

HOW CAN COLLEGES HELP THE WELDING INDUSTRY?

Colleges can do much to help the welding industry by determining its needs and taking action from there.

Perhaps too much stress has been placed upon the bugaboo of "specialization." True, the ideal of engineering education is to produce the whole man, but surely overgeneralization is as unproductive as an extreme in specialization. Again, it may be said that the welding field has become greatly broadened. There are many places within it where one could devote one's entire time and knowledge to but a single phase of this subject. Hence, viewed from this more realistic outlook, the study of welding in its total is a generalization within the engineering field. It has developed far beyond the state of being merely a fabrication method.

The old concept of education was to produce a scholar; today the gap between knowledge and action is ever-decreasing. In plain words, our society, more and more, requires education for production. Therefore, the college is in a position, if it will, to relieve the welding industry of some of the burden of training its personnel. A great many colleges are geared too far in the past as far as production is concerned. An inventory might be made of all engineering courses, relating them to the present needs of industry. Probably a number of bearded practices such as courses in the design of riveted pressure vessels would be turned up as the result. In their place must come courses designed to fit modern practices and even as these become outmoded, new courses must be added. There should be no sacred cows in the college curriculum.

In order to keep college engineering courses in welding up to date there is certainly a need for industrial advisory committees to meet with educators in order to advise them (not to dictate) on policy and scope of their welding program. Colleges can hardly be expected to produce men acceptable to the welding industry without the closest cooperation.

It is quite probable that the welding industry would be willing to lend some of its top engineering, production and sales personnel to be active on such committees. Colleges should also be willing to hear from these men. After such a program is in operation, a long range follow-up study of graduates entering the welding industry could be made to determine how well the course content is serving the industry and the student for an ultimate re-evaluation and strengthening of the college program.

An important bridge between college and industry is the activity of the professional societies. Colleges could well seek the aid of professional societies such as the AMERICAN WELDING SOCIETY and others coming within the scope of their programs.

Among the possibilities open to the colleges for making available more information about welding and its problems are special courses and conferences. Colleges located in the larger industrial areas on the West Coast could be of invaluable service to industry in pre-

senting more evening or short, intensive courses. Such a program is carried on to some extent in the Los Angeles area. The E.M.S.W.T. program offered during the war provided much help to industry. A similar on-going program during normal times, and especially in crucial times such as now, should prove equally beneficial. Such a program has been tried occasionally, but has often failed because of lack of enrollment. To make these programs successful, a closer working with industry seems to be indicated. Needs of the industry must be clear, and incentives for enrollees should be definite.

Welding conferences sponsored by colleges and using experts from industry as speakers and demonstrators offer another avenue for spreading information. One particular need can be filled in holding such conferences for those in the teaching profession connected with industrial arts and metal working. High-school and junior-college teachers have been found to be most receptive to such a program. Often because of their relative isolation, they welcome the help they receive from men actively engaged in the industry. Other selected groups could also be served in this manner.

HOW CAN THE WELDING INDUSTRY HELP COLLEGES?

Realizing that industry cannot and should not subsidize any college welding-training program; nevertheless, industry can give aid and encouragement in other than financial ways. Even with some financial expenditure, dividends will be derived in the long-range, well-planned program. Only with cooperation between colleges and industry can the best interest of society be served.

The action of industry in an advisory capacity has already been mentioned. So, too, has the importance of offering definite incentives to employees taking special courses for further training as offered by colleges.

Field trips have long been an accepted practice whereby industry helps to further education by showing students on-the-job activity. By and large this is an excellent procedure and is one to be encouraged. Actually, however, as a teaching aid, the field trip is too often a form of picnic, mainly because the student is understandably not able, for example, to absorb the entire workings of a steel-fabricating plant in one afternoon. An over-all picture at best can be gained by such an experience. This is not without value, certainly. The same holds true for some company films.

Perhaps a more effective method of presenting typical operations found in the welding industry lies in bringing actual on-the-job work to the classroom itself. This can be achieved with cooperation of industry in providing samples of products on a loan or donation basis, such as welded pipe fittings and connections, as but one example, for classroom analysis and study. Blueprints of actual jobs already built are invaluable aids to a realistic program geared to industry. Textbooks are all right as references, but too often colleges rely entirely upon the book, and the student has no physical or mental contact with actual production jobs. Routing sheets, production schedules, estimating forms and other such paper have the crackle of reality in the hands of the student.

One of the biggest hurdles encountered by the college graduate is that of not having actual work experience. In normal times this adds up to a dilemma for the graduate. He cannot get a job until he has experience, and he cannot get experience until he has a job. One approach for overcoming this difficulty lies in an undergraduate summer employment program for a limited number of students. The ramifications of such an approach are obviously great.

Let us first consider what this practice can do for industry. The problem of obtaining desirable replacement supervisory and engineering personnel is at best a gamble. The application form and the short interview in many cases do not give sufficient evidence of a man's ability or desirability as an employee. On the other hand, the summer employment program offers the employer the opportunity of observing the man at close range as to his potential capabilities. Of course, industry must have a productive place open for such short-time employment. A quick survey of a part of the welding industry on the West Coast indicates that it is receptive to undergraduate summer employment. The openings available will, naturally, not be too numerous. Perhaps about 25% of the juniors about to enroll in a welding option of the mechanical engineering major can find such employment. For the best combined interest of the industry, the college and the man, a selection of candidates should be based upon scholastic standing, high interest in the field, the personality of the student (depending upon the nature of the work involved), along with a final decision resting with the individual within the company who will be in responsible charge.

As to the benefits to the student, this approach enables him to size up his chosen field closely in addition to gaining experience on the job. The college benefits immeasurably in being closely associated with the real needs of industry. Also, junior students returning in their final year are more mature and come back with know-how which radiates to other students and the engineering program in general. The college gains prestige in being able to place its students in desirable positions as a follow-up after the senior year. This in turn perpetuates enrollment in welding courses and assures trained personnel and an advancing interest in the welding industry.

Instructors also have need of brushing elbows with industry in summer employment. Much mutual gain can be realized in this activity. Both industry and the college administration should be interested in encouraging instructors to work in industrial plants during the summer. Too many instructors who have been in education for 15 to 20 years are still teaching the things they knew about when they entered the field.

Whether the instructor is aware of present-day practices, or if he is not, is of considerable influence upon the many students in his classes.

Regular employment is the first step of the college toward the goal of providing society with productive citizens. Employment of graduates well trained in basic fundamentals along with certain specifics is the second step at which point industry takes over. The whole thesis of this paper has been directed toward making this step as reasonable as possible. With specific training in welding carried on by the colleges, industry should not have to bear an undue burden as a part of production.

CONCLUSION

In order to sound out the beliefs of a sampling of members of the welding industry and some of the educational institutions on the West Coast, a questionnaire was developed and submitted. The five questions asked are as follows:

1. From your position in the welding field do you feel that sufficient emphasis is being placed on welding in college engineering courses today?

The overwhelming opinion in this case was in the negative. Apparently far too little emphasis is being placed on welding in college engineering courses. This paper has taken up some of the means of remedying the situation.

2. What is your opinion relative to the feasibility of welding engineering standing on its own along with old-line engineering groups, realizing, of course, that certain fundamental studies are basic to all engineering?

Opinions were divided in this case. They ranged from those favoring a definite welding-engineering major, to a majority favoring a welding option within the mechanical-engineering structure, to a few holdouts for straight mechanical engineering without specialization.

3. What advantages or disadvantages to industry do you foresee in the results of having welding engineering as an established branch of engineering science?

Main advantages to industry included these: That the colleges could furnish industry with men trained to their needs; also that many employers, especially smaller ones cannot carry a man directly from college through an apprentice period; and that because of the increased technical developments, specialization could be of considerable value to the industry. Disadvantages seen were that the term welding engineer might lead the employer to believe that all the man knows is welding. In analyzing this, such would not be the case at all since the man would be well informed as to the fundamentals of engineering. Another disadvantage cited was that of loss of prestige in further splitting up the mechanical engineering field. However, this does not seem an insurmountable disadvantage in the long-range viewpoint. Mechanical engineering has been the proud mother subject of a number of engineering branches which are now established on their own.

4. Would your company be more or less interested in employing a graduate well grounded in welding design and production than in the more general field of mechanical engineering for a position dealing with design and steel fabrication, or sale of such products?

In all cases, an answer in the affirmative was given. Preference was shown for a man with the background named for the employment indicated.

5. Realizing that the welding industry needs both research and production personnel, do you feel that there is a lack of trained production men in welding?

A lack of such men and a lack of men qualified to train them was strongly felt by all of the respondents.

In summing up the case for whether welding should be on its own in education, it appears that this question cannot be answered by a simple "yes" or "no." The direction, however, seems clear. Perhaps in another fifty years or less, a complete affirmative will be reached. For the present, and for the immediate future, the outstanding need voiced by industry is definitely in favor of more and better welding courses in our colleges designed to answer the problems of production within this field.

Stress Concentration Problems in Welded Construction

Factors in stress concentration problems are briefly outlined with illustrative examples and means of mitigation

by G. J. Green and D. H. Marlin

INTRODUCTION

STRESS concentrations, one of the least understood factors today in welded construction, are a source of many problems, real and imaginary, relative to the service life and fabrication details of welded construction. Engineers involved in design and production of weldments are aware of their existence but too often they discuss them in general terms and fail to become inquisitive as to their source or means of mitigation. They are of great importance to anyone concerned with the design or fabrication of a welded structure. A better knowledge of their nature is necessary if we are to further the economical use of welding.

These localized areas of concentration can occur for a number of reasons, and they have marked effect on (*a*) the behavior of a structure in service and (*b*) the cost of fabrication. There has been a great deal of discussion by both technical and nontechnical persons concerning the "rigidity" of a welded structure and how this in turn affects the utility of weldment. A great deal of adverse publicity resulted from the instance of widely publicized failures such as encountered on merchant vessels in the past, and, as a result, many persons have formulated the opinion that the process is unreliable and untrustworthy. The official reports of investigating committees for such occurrences have indicated, among other factors, the importance of stress concentrations as occasioned by improper design or "poor workmanship." Notch toughness of the steel at points of concentration has been similarly shown to be significant. It is evident that practical quantitative data pertaining to the various phases of the problem are needed. Present-day research conducted by the various committees of the Welding Research Council, the Ship Structure Committee, etc., is continually adding to the knowledge of the many factors involved in this complex problem. The necessary fundamental studies require the services of specialists in various fields, and the results will obviously lead to better design and materials and, consequently, better service behavior.

Stress concentrations rarely reach the quantitative value to cause service failure but there can be problems which arise during fabrication operations which plague production personnel and may greatly increase the cost of fabrication. Every welding fabricator has had experience with problems generally evidenced by weld cracking and occasionally plate failures. The cause for difficulties such as these is often blamed in an offhanded manner on the welding operator or the welding electrode, plate chemistry, machine settings, etc. Naturally these factors are significant and of varying degrees of importance to the cause. Frequently, however, the true understanding of the problem lies in recognition of possible stress concentrations.

These production problems should be of concern to engineers as well as production personnel, and a better mutual understanding of their nature is beneficial to the over-all quality as well as economy. A great proportion of welded construction produced today is accomplished by the manual metal arc process. An engineering approach involves detail factors in every major branch of engineering as attested by the increasing amount of effort, in other technical fields, devoted to the study of various phases of welding technology. It is also very evident in the details of the process as we now know it, that the human element plays a vital role in our problems relative to welded fabrication; so practical engineering control of details is necessary in order to reduce its effect.

Stress concentration problems are dependent on numerous factors or conditions. It is interesting to consider some examples illustrating the major factors, means of mitigation and the relative effects.

MULTIAXIAL STRESSES

Briefly, it appears that multiaxial tensile stresses decrease the ductility of steel in comparison to the values observed in the customary tensile test bar. Regardless

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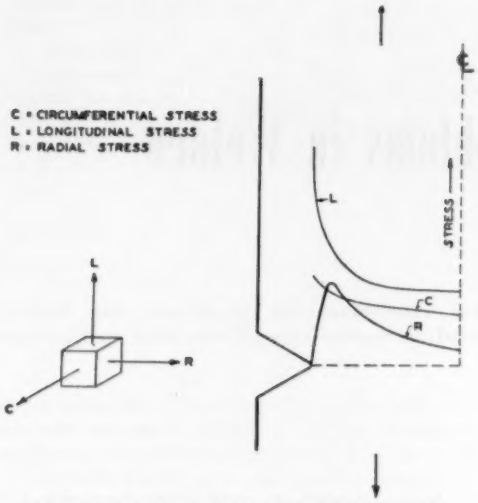


Fig. 1 Notched cylinder in tension. Reference (1)

of how stresses arise, whether by service loads or by fabrication operations, if they concentrate in a local area with a complex multidirectional pattern, that local area will apparently react in a more "brittle" manner, whether it be weld metal or base metal.

THE NOTCH

It is readily apparent that the "notch" plays an important role as a stress raiser, whether that notch be readily visible or hidden from view. The engineer calculates the average stresses in the various components of a structure and adjusts the design in accordance with permissible unit stresses. However, the stresses existing at the notch vary from the average calculated stress in the section. Mathematical analysis of stresses at the root of a notch is not precise, but one factor is very apparent. A multiaxial state of stress exists in a localized area at the root. Figure 1 illustrates the state of stress existing at the root of a notch in a circular bar being pulled in tension. Although in this case the applied stress is in one direction, the resulting tensile stresses at a local increment adjacent to the root are in three directions. This decreases the apparent ductility of the material at this point and, as a result, fracture occurs prematurely at the surface. This small crack has an infinitely small radius at its extremity and since a sharper notch apparently intensifies the stresses, the crack readily propagates under load.

DESIGN

Unquestionably, stress concentrations have effect on the service behavior of a weldment and the engineer must evaluate the relative importance of these concentrations in relation to the anticipated service stresses when considering an economical design. Figures 2, 3, 4 and 5 illustrate diversified types of all-welded structures which have varied types of service stresses. Localized areas of concentrated stresses are of varying importance when considering design details of each.

Fig. 2 All-welded modern river towboat showing propulsion and steering mechanisms

Fig. 3 All-welded "pig traps" for use in high-pressure gas lines. These are subject to high pressure coupled with impact loading

Designers have become aware of the adverse effect of stress concentrations in welded joints and are today giving more attention to the details of their geometry in relation to the tendency for stress raisers to occur in service. Valuable and informative investigations performed by various organizations in association with the Welding Research Council have increased our knowledge of their relative effects. Quantitative investigations of fatigue, such as conducted at the University of Illinois, are a well-known example in which the relative values of fatigue strength for various type joints have been established. When examining the design of fillet weld specimens tested, it becomes apparent that details of weld location are important. Location of fillet welds with respect to any abrupt changes in geometry seems significant.

Notch effects such as generated by ends of fillet welds, sharp corners, and faying surfaces inherent with lap joints and unbeveled tee joints can sensitize a dynamically loaded structure. This justifies the established practice of welding around the ends of tee joints and lap joints on engine foundations, machinery bases, etc.

Such general rules must be justified by service requirements and prudently adopted, since practical production problems can exist which materially affect quality and cost. Fillet welds, particularly at tee joints, show definite evidence of presenting a fabrication problem during welding because of their stress concentrations at the extremities. Figure 6 (serrated angle) shows a tee joint connecting a serrated angle to a plate. This joint is welded "all around" and weld cracking is minimized. However,

Fig. 4 All-welded 75-ton capacity gantry crane

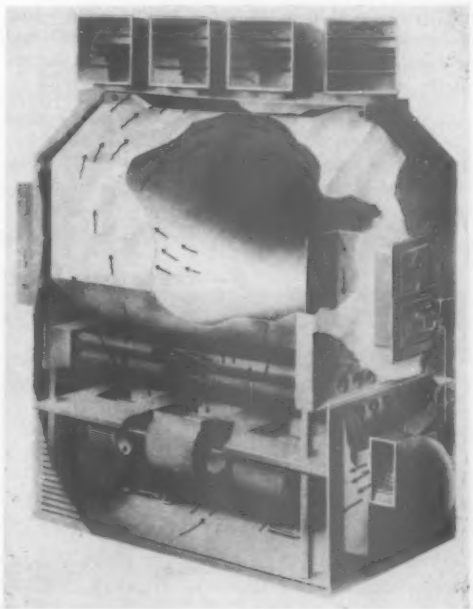


Fig. 5 All-welded unit space heater of 2,000,000 Btu./hr. capacity. High temperatures require use of oxidation-resistant steel in combustion chamber

Fig. 6 Tee joint of serrated angle to plate. Note stress pattern present on mill scale of the plate

it is very easy to "undercut" the upstanding leg at the extremities, using this procedure. This may require excessive repair welding in order to eliminate the notch in the angle. Ending both welds at the extremities without welding around the ends results in an increased tendency to crack both the start and the end of the "second side" fillet. Other factors, as it will be pointed out later, can affect the tendency to crack at these points but it was noted that stopping the fillet welds 1 in. short of the ends with the first side fillet slightly shorter in length, decreased the cracking tendency.

The relative value of stress concentrations in a structure is dependent upon the rate of loading, temperature of operation and fluctuation of both thermal and mechanical stress. Mechanical reversals of stress are readily recognizable in many structures and their intensifying effects are easily seen. Equipment operating at elevated temperature, particularly when the temperature fluctuates, also requires careful consideration as to design details. Thermal stresses can be generated by a relative difference of thermal expansion in two members welded together as occasioned by (*a*) difference in temperature or (*b*) difference in coefficients of thermal expansion of the member components. These stresses reach high magnitudes at the welded joints and become critical at local areas involving notches or sharp changes in geometry of the joint.

Figure 7 portrays a typical example wherein a tee joint is used to attach an austenitic stainless steel bar by austenitic stainless steel welds to a bent mild steel or ferritic stainless steel plate. The austenitic stainless bar has a 55% higher coefficient of thermal expansion than the plate and it is readily apparent that thermal stresses can arise in this area when operating at elevated temperature. If the fillet welds are extended to the top of the joint a highly concentrated area of stress results in the plate during service due to the sharp change in geometry, as well as the added restraint occasioned by the presence of the bend; however, if the weld is stopped short of this point, danger of cracking is removed. Figure 7 (*B*) indicates the critical area occasioned by a sharp change in direction of a fillet weld. Here again, the differential in thermal expansion of the members and/or a differential in temperature existing between them can generate high stresses which, in turn, concentrate at a local area when a weld is extended around the corner. This condition can be further aggravated by presence of notches or added restraint from bends or other welded connections in the immediate locality.

Multidirectional stresses can be generated also by

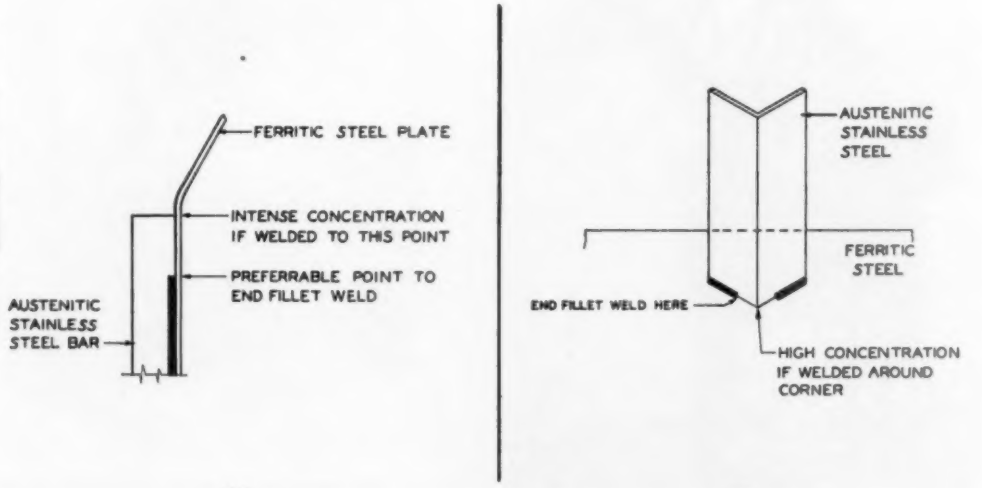


Fig. 7 Examples of thermal stress concentration at elevated temperatures

Fig. 8 Plate crack in area where numerous welds intersect

excessive welding in a localized area. Complicated stress systems, thus occurring, are known to cause "brittle" behavior of steel. Figure 8 illustrates a fracture that occurred some years ago during fabrication when the steel pad was erroneously welded adjacent to the mutual intersection of many fillet welds. Such "brittle" behavior seems to be dependent also on "notch toughness" of the steel at a given temperature.

WELDING DEFECTS

The undesirable features of welding defects have long been recognized. Welding inspectors are constantly alert for undercuts, craters, overlap, etc.—all visual defects which are readily seen. There can be undoubtedly many defects not visible to the eye such as unfused roots, slag pockets and gas holes.

What is the quantitative effect of these defects? Often they are adjudged solely on the basis that they reduce the critical cross section and subsequently increase the unit stress. However, it would be logical to expect that they also act as a "notch" and hence as a source for stress concentrations. Photoelastic studies have been made on celluloid models simulating various welded joints with defects[2, 3] and various concentration factors were obtained for the models studied. It is recognized that welding defects, because of their shape, are hard to reproduce in a model, so as a preliminary study semiquantitative tests were performed on a number of butt and tee joints purposely welded with defects included. These specimens were sectioned transversely and machined with a parallel cross section. The "brittle lacquer" technique, using "Stresscoat," was employed to identify the locations in these specimens of possible stress concentration points. The test procedure consisted of (*a*) machining parallel cross sections from the coupon so that the specimen section had an area of about .0.5 in. These parallel surfaces were ground smooth; (*b*) a brittle lacquer Stresscoat was sprayed on the machined cross section. This lacquer had a uniform thickness over the entire area and bonded to the metal. It had a strain sensitivity of 0.00076 in. per inch. The lacquer would crack at a given strain rate when the underlying metal reached a stress of approximately $(30 \times 10^6) \times (7.6 \times 10^{-4}) = 23{,}000$ psi.; (*c*) the specimens were pulled in tension, starting at low loads and subsequently increasing the load until a lacquer crack occurred at one of the defects in the joint. This procedure was continued until cracks had appeared at all defects or until general cracks appeared in the lacquer coating on the base metal.

Such a procedure visually indicates the areas of local concentrations at the joint surface and affords some measure of their relative intensity at various defects on the particular specimens tested. Obviously, the most serious defect will cause a local concentration of 23,000 psi. (coating crack) at lower values of load than the less serious type. The concentration factor of a particular defect was calculated by noting the load at which an area at the defect reaches 23,000 psi. Knowing this load and the area of the base metal, the average unit stress in the base metal can be easily obtained. Subsequently dividing 23,000 psi. by this average stress gives the relative concentrating value of the particular defect.

Figure 9 illustrates a stress pattern generated in the lacquer when the specimen was loaded sufficiently high to crack the lacquer on the base metal. Note the pattern in the vicinity of the defect—the cracks first appeared at the defect at lower loads than that necessary to cause over-all cracking. Table 1 indicates the results observed when calculating the concentrating factor in six butt-welded specimens in $^3/_4$-in. plate.

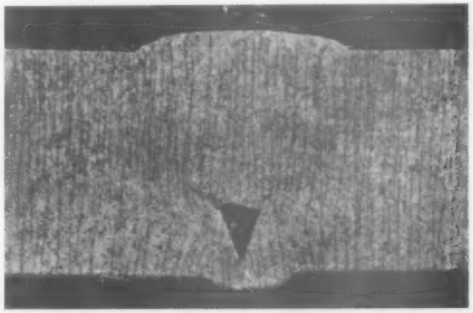


Fig. 9 Lacquer cracks illustrating stress distribution around defect in Specimen D, Table 1

Specimen was loaded in excess of 23,000 psi. unit stress in base metal. Cracks appear at right angles to direction of principal stress

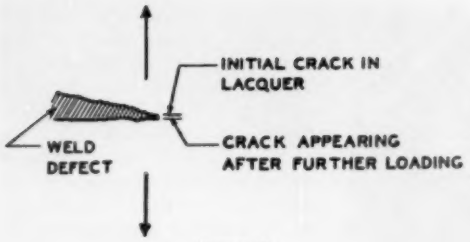


Figure 10

It is well to remember that these figures are only approximate, as the experimental technique was not designed for maximum accuracy. There was some evidence of bending stress present due to slight bending of the specimen axis. Similarly the values shown are not based on nominal unit stress of the cross section at the defect. Actually, if done, this would decrease the factors for all defects, but the relative values would be of about the same order. It is also noted that this method indicates the state of stress on a free surface affording opportunity for the existence of only two directional stresses.

The object was to observe the relative values obtained for the various defects and certain interesting observations were made.

1. It was noted that lacquer cracks first formed at the defect as a single crack of short length.

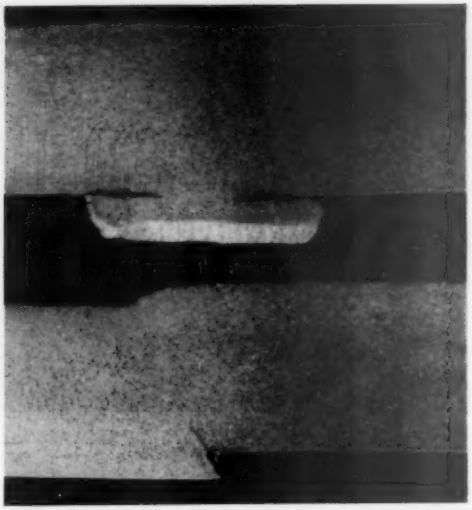


Fig. 11 Comparison of stresscoat cracks in a butt weld made with a backing strap (Specimen N, Table 1) and a poorly welded misaligned butt joint (Specimen Z)

Initial crack in unfused root of Specimen Z occurred at one-third of the load needed to cause initial cracking shown in Specimen N

Further application of load did not immediately elongate the crack but a second short crack appeared adjacent to the initial one. This is illustrated in Fig. 10 and appears to be

Table 1—Stress Concentrations at Welding Defect, Brittle Lacquer Technique*

Spec. No.	*Section*	*Base metal area*	*Defect*	*Load to crack lacquer at defect, lb.*	*Av. stress, psi.*	*Local concentration factor (approx.)*
D		0.554	1. Large unfused area	10,500	19,000	1.2
G		0.550	1. Unfused center 2. Heavy reinforcement	4,000 10,000	7,275 18,200	3.1 1.3
N		0.553	None	Entire section cracked at 23,200 psi.		1.0
X		0.550	1. Unfused root slag pocket 2. Undercut	5,000 12,000	9,190 21,800	2.5 1.1
Y		0.555	1. Unfused root	7,000	12,600	1.8
Z		0.558	1. Misaligned unfused root	4,000	7,160	3.2

* Lacquer cracks at approx. 23,000 psi.

definite evidence of local yielding, which has long been assumed to be true at such points. Local yieldings would tend to mitigate the concentration and redistribute the stresses.

2. The undercut in specimen X showed a comparatively slight amount of concentration. Repetitive trials bore out this fact.
3. Unfused areas either at the root or in the center show high values. These defects are sharp notches and probably their shape and direction accounts for the high values obtained. Bending stresses at the root of the eccentric joint Z increase the concentrating factor.
4. Slag pockets or voids of comparatively large diameter indicate lower factors.

The number of tests is of course insufficient for use in formulating definite evaluations. However, further refinement of the basic technique and a systematic application to various joints should give a better understanding of the relative values of these defects which in turn could be used as a guide for practical evaluation in inspection and design.

There is a definite need for the design engineer or detailer to recognize the working limitations of the welder. Industry is indeed so greatly dependent on the "human element" in manual welding—so much so that details of joint design must be of a nature to minimize the occasion of defects such as incomplete fusion, excessive slag entrapment, etc. All the defective samples shown in Table 1 were readily produced by preparing joints with insufficient bevel, excessive land or narrow root openings. Note that Fig. 11 illustrates the stress distribution at a butt joint made with a backing strap or "ring" as in pressure piping, compared with a butt joint with insufficient bevel and no root opening. Without a backing ring the joint edges should be spaced more closely together to facilitate welding the root bead. Unless great care is taken during fitting operations, a "tight" fit may occur, possibly resulting in incomplete fusion and the evident stress concentration at the unfused root. One might compare this to the lack of concentrations in the joint containing the backing bar. The effect of the notch shows itself clearly.

FABRICATION TOOLS

The burning torch, chipping hammer, shears and heat straightening torch are useful and necessary tools in welded fabrication However, their misuse can also be the source of a number of problems related to stress concentrations. Dull or misaligned shear blades can cause deformed edges that may prove troublesome. Carelessly used chipping tools will result in comparatively sharp notches. The heat straightening torch inherently generates a complicated stress pattern which unless properly controlled can result in high multiaxial stresses in localized areas that in turn may cause cracking. We are all aware of the sharp notches that can be formed by misuse of a burning torch, and reaction stresses formed during subsequent welding operations can initiate failure at such notches.

Caution should be exercised in torch burning heavy sections of higher hardenability steel. The formation of microscopic cracks in a brittle martensitic zone adjacent to the kerf can lead to cracking difficulties. The effect of microscopic cracks in fusion zone areas is illustrated by the successful use of low-hydrogen type electrodes for elimination of underbead cracking at the fusion zone of welds made on higher carbon or alloy steels. Small cracks occur at the fusion zone when we use conventional steel electrodes, and these cracks initiate failure at the fusion zone. Elimination of the cracks in turn removes a major cause for failure and makes the material more weldable.

While circumstances such as illustrated may be a possible source of trouble, other factors can tend to aggravate the condition. It is obviously desirable to keep reaction stresses to a minimum in those areas where stresses can accumulate; therefore, the specification of a properly engineered procedure combined with correct welding techniques is also important.

WELDING PROCEDURES

It is well-recognized practice in welded ship construction to use a planned welding procedure for welding the various joints of plate and framing. Ship structures

Fig. 12 Illustrating symmetrical procedure used during erection of 450-ft. floating drydock. Note sidewise declination

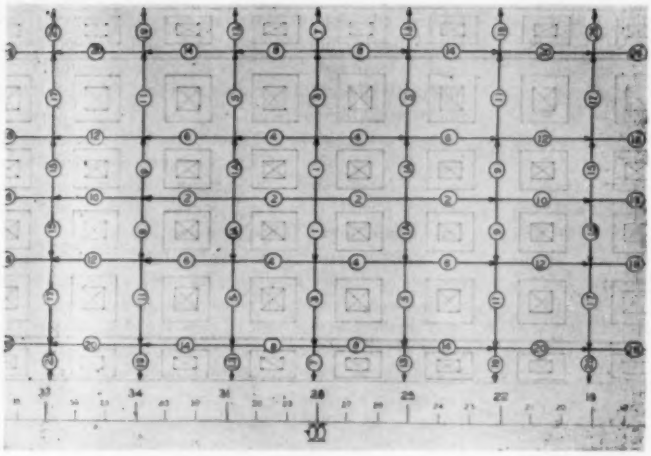
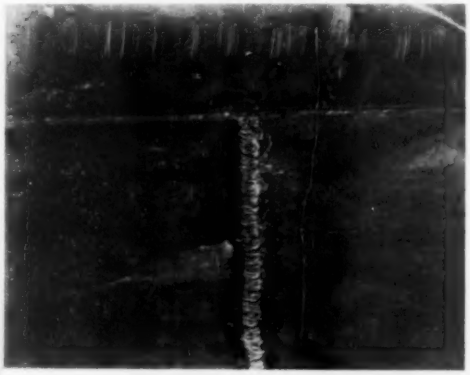


Fig. 13 A portion of the general welding procedure schedule used for erection of drydock shown in Fig. 12

beneficial for controlling distortion and decreasing critical areas of stress concentration. Figure 12 illustrates a large 6000-ton drydock that was completely welded in accordance with a previously planned erection and welding procedure. Specifications usually state that welding shall begin at the mid-point of the structure and proceed outwardly in a symmetrical manner. Welding procedures require careful planning so as to permit a maximum number of men to work in a desirable sequence. Erection scheduling is intimately keyed with this formula. It is usually preferable to erect separate subassemblies for subsequent erection according to a general pattern. Close observance of Fig. 12 indicates the symmetrical manner in which this structure was erected and welded. Figure 13 reproduces a portion of the general welding procedure diagram for welding the numerous subassemblies together.

usually have a complicated geometrical detail involving intersecting welds of all types. A planned procedure is



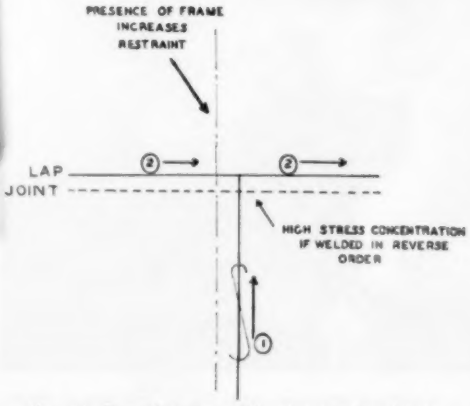


Fig. 14 Procedure for welding intersecting joints

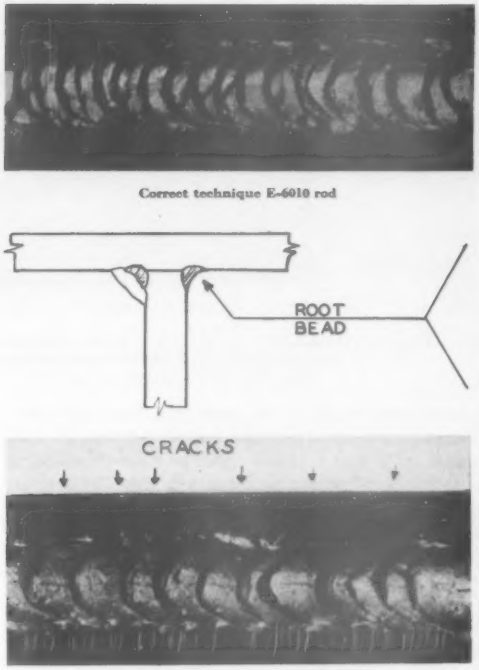
Areas of concentration can easily occur at intersections of plate welds; so here the general welding procedure must be regulated in such a manner as to permit the proper sequence of welding at these points. Figure 14 shows the established practice of never welding past an unwelded intersecting joint. The vertical butt joint is welded first, and the intersecting horizontal lap joint is left unwelded in this area, until the butt joint is completed. This general rule applies to all plated structures—when it is not followed, areas of complex stress conditions will occur at the area surrounding the joint intersection which in turn can result in possible failure, by cracking, of welds or base metal. Any added restraint brought about by framing members welded in the immediate vicinity will make this condition even more critical. The ability to crack has been observed to be dependent on the crack sensitivity of the steel plate. When cracks occur, they propagate at the speed of sound with a characteristically loud report.

WELDING TECHNIQUES

A great number of problems arising in production are traceable to details of the welding techniques used. This is one matter which is frequently overlooked and may prove quite troublesome unless properly evaluated and controlled. The welding technique used by the welder for various type of joints is directly related to cracking difficulties in weld metal occurring when stress conditions become critical. Frequently weld metal cracks are entirely blamed on other factors such as composition of the steel welding electrodes, amperage, dirt, etc., and undoubtedly these factors are important. However, closer examination of the difficulty is often fruitful—revealing points of stress concentration —which, coupled with the technique, are the basic

Fig. 15 Illustrating the presence of a small crack at the beginning of a "second side" fillet weld on a tee joint

source of trouble. A few typical examples may prove interesting. Experience has shown that when welding both sides of a tee joint, the "second side" fillet is more susceptible to cracking through the throat. Deep craters are a common location for such cracks, but often partial cracking is found in the beginning of the fillet weld. Figure 15 illustrates such a crack. This is a single pass fillet welded with an E-6013 type electrode. The technique of welding consisted of starting at one end and welding continuously to the other. Figure 16 shows etched cross sections of this same weld. The section at the crack readily reveals a decided lack of penetration, while the same weld sectioned at midpoint is acceptable. It is thus seen that the insufficient penetration, coupled with the inherent notch present, generated a stress condition resulting in a fine crack.



Correct technique E-6010 rod

Incorrect technique E-6010 rod

Fig. 17 Effect of technique 2 pass overhead fillet

The lack of penetration was due to the chilling action of the cold base metal at the point of initially striking the arc. An obvious solution for increasing the penetration was to backstep the welding at the starting area. Other factors such as chemistry of base metal and/or electrodes may aggravate this cracking tendency.

Figure 17 illustrates the effect of technique in causing cracks in a two-pass overhead fillet. With the occurrence of intermittent cracks of varying length in the finished weld, close examination revealed that small

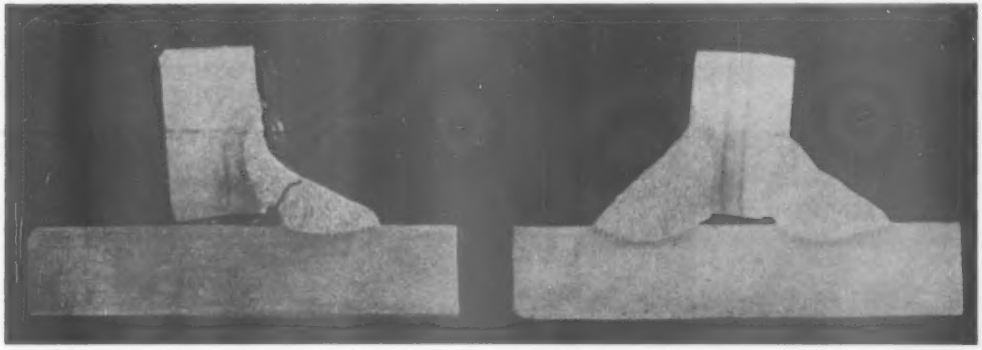


Fig. 16 Macroetched cross sections of fillet weld shown in Fig. 15

The section on the left was removed from cracked portion at the start of the weld. The left-hand fillet weld of the specimen on the right illustrates cross section at the center of the weld

Fig. 18 Brittle failure of 5/8-in. plate in a simple preassembled plate section. Cracking occurred in storage prior to erection

brittle, "cast iron" appearance of the fractured surface may be surprised to find that subsequent tests on the material indicate that it is well within specification limits as measured in tensile test. Occasionally dramatic examples can occur which illustrate this fact. Figure 18 is a case in point where such a plate failure occurred in a simple preassembly. A series of angle stiffeners had been welded to a plate with a tee joint. With no visible evidence of damage, the plate fractured during storage, with the failure extending inward from a free edge and around the end of the tee joint. Chemical and physical properties were within specification limits for mild steel weldable quality plate. Similarly, cracks have been observed in plates during fit-tack welding of assemblies prior to strength welding. Figure 19 illustrates the occurrence of such a crack at the end of a tack weld. These examples occurred some years ago and are, fortunately, rare. However, they involve presumably mild areas of stress concentration and indicate that the steel was comparatively "crack sensitive." The decrease of notch toughness with temperature as defined by "transition temperature" has been well known for many years—particularly when applied to dynamic loading conditions. But only in the past few years have we become more aware of its importance as related to areas of stress concentration during static loading conditions.

intermittent cracks in the root bead were the cause. The electrodes used were the reverse polarity, all position E-6010 type. It was noted on close examination that fine hair cracks occurred in only some of the beads of weld, and that these beads were widely spaced and concave in section. Again the inherent notch in the joint generated throat cracks. These wide "beads" were evidence of a too high speed of deposition. The particular E-6010 electrode used had slag characteristics which permitted this high rate of deposition. Since the obvious answer was to obtain a narrower length bead, and because it is difficult to insure that a welder will do this (particularly if on incentive rate) the desired bead contour was achieved by changing the electrode to an E-6010 type with less viscous slag and a "harsher" arc characteristic. Thus, engineering control of material offset a human element factor and resulted in a practical solution of the problem. Further, it was noted that plate or electrode chemistry (relatively small increases in sulphur content) aggravated the problem.

Fig. 19 Crack occurring in 5/8-in. bulkhead plate during erection
Crack extends from end of small tack weld. Note that strength welding has not been done. Cracked edge has been beveled with a chipping tool

RELATED METALLURGICAL FACTORS

The metallurgical and chemical characteristics of both base metal and welding electrode are vitally related to the manner in which a welded joint will react to these areas of stress concentration. Subtle changes in chemistry and manufacturing processes for these items reflect the frequency of cracking difficulties. Physical property specifications, as commonly used, do not necessarily control the "crack sensitivity" of the materials at locations where stress conditions are complex and critical. The physical property requirements for steel are usually determined by bend and tensile specimen tests with a certain few exceptions such as A.S.M.E. code restrictions for material used on pressure vessels operating at low temperatures. All are aware of the valuable research being performed in the study of notch toughness or crack sensitivity of steel, its relation to temperature and its effect on general weldability.

Anyone who has encountered instances of cleavage fracture under static loads, with the characteristic

Weld metal cracks during fabrication can prove troublesome and costly. It is axiomatic to state that the frequency of occurrence is dependent on weld metal chemistry. Obviously, the chemistry of weld metal is

dependent, in turn, on the chemical ingredients of both welding electrode and base metal. A seemingly slight increase of residual elements and impurities in commercial analyses of steel, although apparently superficial at first glance, can increase the tendency toward cracking at local points of stress concentration. It has been observed, for example, that if all the component ingredients of a welded joint are on the "high side" of accepted limits on sulphur, the possibility of weld metal cracking difficulties increases. If only one of the components is at the upper limit, the frequency of occurrence is much less.

It is realized that there are many practical problems involved in the manufacture of the greatly increased volume of steel and welding electrodes needed for present-day production requirements and that too restrictive a specification would not be in accord with today's manufacturing processes. However, it is hoped that research now under way will lead to a better understanding of this subject and the subsequent attainment of a practical answer relative to specifications. It is further noted that these metallurgical factors only aggravate the occurrence of production and service difficulties—they are not, in themselves, the source.

CONCLUSION

In conclusion, it is evident that the examples cited only briefly indicate some practical instances of the importance of stress concentrations in present-day welded fabrication. They are a major source for many of our problems both in service and during fabrication, and it is necessary for engineers as well as production personnel to pay particular attention to details, in order to eliminate them.

A marked expansion of the use of welding during recent years has spotlighted many weak points in our knowledge with regard to the nature and effect of stress concentrations. The welding engineer is often forced to apply "hit and miss" methods to affect a quick and presumably simple solution. A better quantitative knowledge of the nature and effect of stress concentrations seems desirable. This, in turn, with proper evaluation, will obviously prove a valuable guide to both the designer and to production personnel as well as help eliminate many unwarranted suspicions which can hinder the progress of welded design.

ACKNOWLEDGMENT

The authors wish to acknowledge the helpful and able assistance of Mr. Stanley Brosky and Mr. John Gibbons of Pittsburgh Testing Laboratories in the preparation and testing of Stresscoat specimens indicated in this report.

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(Continued from page 596)

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CORRECTION

In the article entitled "Cast Weld Construction," by Jack Osborn Felt, published in the May 1951 issue of THE WELDING JOURNAL, the printer inadvertently dropped 11 lines at the top of page 423. This paragraph should read as follows:

> Foundry process control by statistical methods accomplishes at least six major objectives, it was reported by D. Meves and J. Ferrell, West Michigan Steel Foundry Co., Muskegon, Mich. As discussed by Mr. Meves, they are: (1) Clearly define process levels so that when a process change is made, the effects of change are readily discernible; control charts present graphic proof as to the merit of change. (2) Clearly show where most time should be spent to eliminate scrap and rework; control charts direct the attention of trouble shooting where it is most needed. (3) Develop cost consciousness by providing a graphic picture of foundry operations and associated costs. (4) Provide means of determining the effects of many variables on casting quality. (5) Guide management by providing a clear and concise picture of foundry operations. (6) Show, probably most importantly, when trouble is developing, rather than when it is fully developed.

Sigma Welding of Nonferrous Metals and Alloy Steels

Hand and machine shielded inert gas metal arc welding of aluminum and copper and their alloys and hard facing application

by H. T. Herbst

INTRODUCTION

HELIARC* welding apparatus using a nonconsumable tungsten electrode in an inert-gas atmosphere has become an important tool in the past eight years. Its acceptance has come about largely because of high quality of the weld metal. This quality is due principally to the inert character of the shielding of the weld zone. The advantages of inert-gas shielding have more recently been applied in a consumable electrode type of welding wherein the tungsten electrode is replaced by a continuous length of welding rod. Heat liberated by the arc causes melting of the filler rod into small droplets which are transferred across the arc to the work.

The purpose of this paper is to describe the major principles of the functioning of this process and to show by examples some of the ways in which it is being used. The subject matter will deal with hand- and machine-welding methods as applied to the welding of aluminum and copper and their alloys. It will also describe certain build-up and hard-facing applications. Apparatus commonly employed will be described and a comparison of various types of welding power will be briefly mentioned. Economic considerations in these applications will be stressed to show the importance of the high deposition rate available with this process.

DISCUSSION

General Considerations

In the shielded inert gas metal arc process the necessary heat for fusion is obtained by an arc between a consumed filler rod and the work. In general, the size and type of workpiece will dictate the amount of welding current necessary for satisfactory results. With this amount of current in the arc a certain amount of filler rod will be consumed, which amount cannot readily be changed except within extremely narrow limits. Therefore, unlike Heliarc welding, the amount of weld metal which will be deposited cannot readily be controlled. For this reason, as in other metal arc welding processes, there is likely to be some lower limit on the thickness of metal which can be welded practically. Where metal is extremely thin, the amount of reinforcement which will result by melting of the electrode will in many cases be excessive and require metal-removing operations. While the use of small diameter rods yields more stable operation on thin metals, the amount of metal which is deposited by these small sizes is not particularly less than would be deposited by rods of larger diameter.

To some extent the satisfactory operation of the process depends upon a relatively high current density, that is, amperes per square inch on the electrode. At low currents this calls for an extremely small rod size. The combination then of the excessive metal deposition rate and the requirement for small rod sizes will generally indicate a minimum thickness for the shielded inert gas metal arc process in the neighborhood of $^3/_{16}$ in. This is purely a generalization since unusual requirements may make it possible to weld thinner materials or prevent the use of the process on even thicker sheets. Again, production of fillet welds will frequently allow, under equal conditions, the use of the process on thinner gages than could be justified for butt welds.

Most of the common types of joints and positions for welding readily accomplished by other methods can be undertaken with this process. Here again the dependence on high current densities for stable operation will in general call for smaller diameter filler rod in conjunction with the lower currents necessary on position welding. In general, therefore, the thinnest material which can be welded with this process under like

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* The term "Heliarc" is a registered trademark of Union Carbide and Carbon Corp.

conditions will be somewhat greater for position welding than will be accomplished in the flat welding position.

Requirements in the way of cleaning are not unusual and correspond for the most part to those required for Heliarc welding. In some cases, principally because of the type of welding power used, cleaning requirements will be found to be less stringent for the shielded inert gas metal arc process than for "Heliarc" welding.

WELDING EQUIPMENT

The complete equipment required for shielded inert gas metal arc welding consists of a welding rod driving mechanism, gas cup and rod guiding assembly, welding power supply source, an inert gas supply source and gas control equipment. The first two items constituting the rod feed mechanism and the gas cup and rod guide assembly are generally integrated in one assembly for machine welding. For hand welding, the driving mechanism is stationary, while the cup and rod guide assembly is fashioned into a hand unit for easy manipulation. The two are connected by a flexible conductor for the welding rod, shielding gas, cooling water and power supply.

When a proper balance is established, welding rod may be fed into an arc at a constant rate and will melt off at the same constant rate, thus maintaining a uniform arc length. This phenomenon is observed for arcs in inert atmospheres as well as in other mediums. In order to attain proper balance a relatively small diameter welding rod must be used to produce a high current density at the end of the rod. The rate of rod feed must be adjusted to the critical speed which will produce the arc length desired, and this speed must be maintained within close limits.

In the case of the arc at high current densities, as the arc tends to shorten, the arc voltage drops causing the rate at which the welding rod melts off to increase, thus tending to lengthen the arc. Conversely, when outside influences tend to lengthen the arc the melt-off rate decreases, thus automatically shortening the arc length. In addition to this factor, the sloping characteristic of direct-current welding generators is such that as the load (arc length and voltage drop) decreases, the current output from the generator increases. The increase in current causes the rod to melt more rapidly, thus lengthening the arc. Conversely, as the load increases (arc length and voltage increase), the current output from the generator decreases. This decrease in current results in slower melting of the rod thus shortening the arc length. These two factors therefore work simultaneously to automatically maintain the arc within reasonably close limits. In other words, the arc is said to be self-regulating.

In general, the higher the current density the more closely does the arc maintain its preset condition. In hand-welding operations, for ease in manipulation, rod sizes up to $^{3}/_{32}$ in. are employed. With these sizes the current density can be maintained at a level to provide

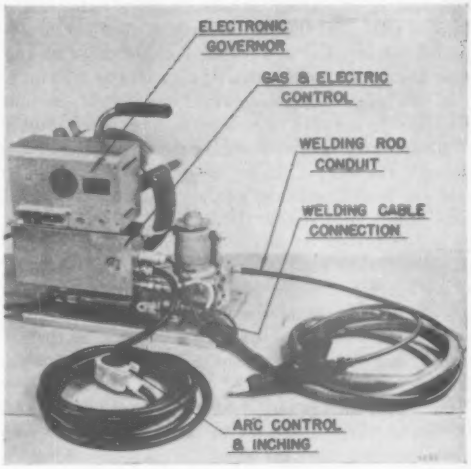

Fig. 1 Assembly of hand-welding equipment

satisfactory operation with a constant rate of rod feed. Therefore, hand-welding equipment has been provided in which the rate of rod feed is maintained substantially constant by a governed motor, but it can be manually adjusted over a wide range of speeds.

Such an assembly is illustrated in Fig. 1 which shows the complete rod feeding and welding assembly. In this equipment the drive motor shown at the extreme right is operated at a constant speed within its operating load range by an electronic governor. This governor maintains the speed constant regardless of temperature or power line variations. The desired rate of welding rod feed is obtained by means of a small potentiometer mounted on the end of a flexible cable shown in the lower right-hand corner of the illustration.

In addition to the motor and governor, the illustrated assembly incorporates a gas and electric control system. The purpose of this system is to synchronize shielding gas flow and operation of the motor with the action of the arc. In starting a welding operation the gas flow is first initiated and the control circuit made ready by pressing a trigger located in the handle of the welding torch. The unit is ready for operation as soon as the operator touches the end of the filler rod to the workpiece. When the voltage at the arc drops from the open-circuit voltage of the generator to that of the arc the motor is automatically set in motion to feed welding rod. This operation continues until such time as the operator wishes to stop. The arc may be stopped by either rapidly raising the torch from the work, thus breaking the arc and automatically stopping the feed motor; or the arc may be extinguished by again pressing the trigger on the torch. This will operate a relay that cuts off the welding power and automatically stops the rod feed.

In this assembly, welding rod is supplied from a small reel mounted directly to the rear of the motor.

This reel is adjustable to accommodate wide weight range of coils. At the present, coils of aluminum welding rod are supplied in a nominal weight of 10 lb. and other materials in coils with a nominal weight of 25 lb.

In machine-welding operations where lightness and flexibility do not tend to dictate small rod sizes, greater economy of the operation can be gained in many cases through the use of larger welding rods. Although economy is obtained through the use of larger diameter rods, ability to maintain the arc length automatically by self-regulation is sacrificed thereby. In order to ensure constant conditions at the arc, it is necessary at low-current densities to resort to an arc length control device. These devices usually operate to increase or decrease the rate of feed of welding rod as the arc length, and therefore voltage, tend to increase or decrease.

Several of the arc length control devices available on the market were tested for use in controlling rod feed in the shielded inert gas metal arc process. However, it was determined that the changes in arc voltage for a given change in arc length are relatively small in this process, and these devices were not suitable because of lack of sensitivity. An entirely new type of arc length control has been developed having greater sensitivity to voltage fluctuation than commonly available types, and it has been found to perform most satisfactorily for many argon metal arc applications.

Such a control is available in a welding-machine assembly illustrated in Fig. 2. Although this control is essential for certain kinds of welding, it does not fill all of the requirements. The machine illustrated in Fig. 2, therefore, incorporates means for driving the welding rod at a uniform rate by governed motor action. Thus this welding machine is capable of being operated to control the arc length in either manner depending upon the type of material being welded. Selection of the type of control is by a simple switching arrangement.

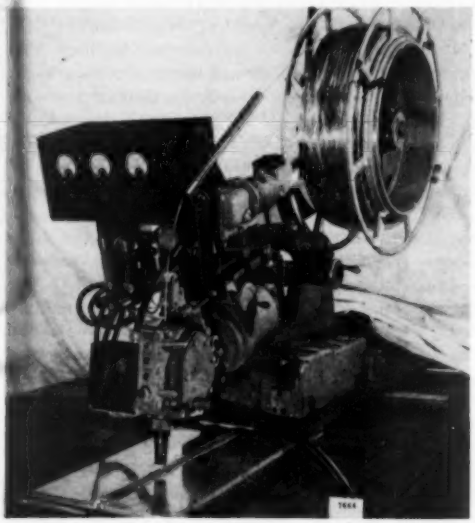

Fig. 2 Assembly of machine-welding equipment

The current capacity of this welding machine is rated nominally at 500 amp. and can be operated at welding rod feed rates of from 50 to 250 or 100 to 700 in. per minute depending upon gear selection. It will handle welding rod of from $^1/_{32}$ in. diameter up to and including $^1/_8$ in. diameter. The change from one to the other is accomplished by simple switching. This unit may be mounted on a tractor for portable operation or may be in a fixed position where it is desired to move the workpiece.

This machine-welding assembly also incorporates a control circuit to synchronize the starting of the rod feed motor with the initiation of the arc. The arc is started by momentarily shorting the end of the welding rod to the workpiece by means of a length of carbon rod. Facilities are also provided for inching the rod up and down in establishing conditions preparatory to starting the arc. In order to provide longer periods of operation before it is necessary to replace the coil of filler rod, a larger rod reel is used on this machine assembly. This reel is capable of holding 50 lb. of coiled aluminum rod or 150 lb. of various other metals.

Welding Power Supply

Direct-current welding power may be supplied by standard welding units of the rectifier or generator types. For most welding applications, reverse polarity (electrode positive) is most suitable. Straight polarity may be used for some special applications. Alternating current is usable, but somewhat special types of transformers not readily obtainable are required. The operations described in this paper are all performed using reverse polarity direct current.

In selecting the size of welding power supply unit the possible duty factor at which the machine may be operated should be considered. Since the welding rod is supplied from coils, welding may be continuous for the full length of a seam. In machine-welding operations uninterrupted arc time of 45 to 60 min. is not uncommon. In hand welding, operator fatigue and the necessity to change position will dictate shorter periods of arc "on" time. However, since it is generally unnecessary to perform any cleaning on the crater before restarting the arc, duty factor can be much higher than commonly experienced in flux-coated rod welding methods. In selecting a welding machine these factors should be borne in mind since they may require a larger machine for similar current levels than for other welding methods.

As in Heliarc welding, no significant influence on the arc characteristics has been detected by reasonable variations in the open-circuit voltage. Other things being equal, open-circuit voltages from 70 volts to the maximum available in common welding machines do not seem to influence the characteristics of the arc. While satisfactory operation may be obtained at lower

open-circuit voltages, special care is sometimes necessary in adjusting the starting circuit to work with such lower open-circuit voltages.

THE WELDING ATMOSPHERE

Although this is a bare-rod welding method, the arc and weld are extremely well shielded from the air by the inert gas envelope. In addition to physically shielding the arc, the gas provides a conductive path for the arc. The kind of inert gas used determines characteristics of the arc and the results obtained. Both argon and helium and mixtures of the two have been tested. When welding aluminum with reverse-polarity direct current, the oxide layer is removed from the surface of the material, probably by ion bombardment. This interesting phenomenon is beyond the scope of this paper but is covered more fully elsewhere.[1] This oxide removal or cleaning action is much more pronounced in argon than in the helium atmosphere.

Application of this theory to this process explains the following facts established by experiment. In reverse-polarity direct-current welding when using argon there is less spatter and approximately 50 to 75% as much gas flow is required as when using helium. It is believed that the ion bombardment results in a force on the particles of metal melted from the electrode. When using reverse-polarity direct current this force is in the direction toward the plate. This results in acceleration of the droplet of welding rod being transferred. The velocity of the droplet thus attained prevents other forces at play in the arc stream from deflecting the droplet. Any droplets which are deflected too far from the central core of the arc are discharged out of the gas stream and result in spatter. The greater density and, therefore, the greater ion bombardment and resulting acceleration force is believed to account for the lower degree of spatter in argon than in helium.

It is observed that the weld bead is in general somewhat wider in helium than in argon. This is possibly a result of deflection of rod droplets from the center of the arc. The foregoing theoretical considerations seem to fit the observed experimental facts very well. Studies made on the action of metal droplets being transferred across the arc by means of high-speed photography yield similar agreement. Some of these studies are described elsewhere.[2]

WELDING ALUMINUM

The shielded inert gas metal arc welding process is well suited to the welding of aluminum and several aluminum alloys. Naturally, the most outstanding feature that commends it for this work is the absence of flux and associated cleaning and corrosion problems. In this respect, it is equivalent and similar to the Heliarc process. The shielded inert gas metal arc process offers considerable advantage in rate of welding due to the ability to deposit metal with adequate fusion at higher welding rates. This, of course, results in economies in time and gas consumption. Such economies are particularly important in materials of greater than $^1/_8$-in. thickness.

The rapid welding rates possible with shielded inert gas metal arc welding call for some special care to prevent porosity. Welds of acceptable quality to pass X-ray examination by the various codes can be produced by both Heliarc and shielded inert gas metal arc welding. When welding aluminum with either inert gas process the rate of cooling of the weld puddle exerts some influence on the porosity in the final weld. At the very high welding rates that are used in machine welding of gage thicknesses of material, the metal is melted and fused and solidifies at a very rapid rate. Under these conditions the weld bead is found to be free of porosity. At lower welding rates, particularly when using filler rod, gas does occur in the weld metal. If the weld puddle is sufficiently fluid this gas rises in the fluid metal and escapes, resulting in a porosity-free weld. Because of the relatively large and fluid puddle typical of the Heliarc process, the escape of gas is practically assured under all conditions. Thus, no particular care is necessary to avoid porosity other than to attain adequate penetration.

The puddle produced by the shielded inert gas metal arc process is not as large and freezes more rapidly than that produced by Heliarc welding. Under some operating conditions this results in gas bubbles being trapped in the weld puddle, resulting in porosity. In general, welding rates may be adjusted to produce the satisfactory cooling action. Because the formation of porosity does depend on the solidification rate, the range of solidification of the particular aluminum alloy will influence results. Thus the pure metal designated 2S with its narrow solidification temperature range of 1190

Table 1—Typical Welding Conditions 61S-T Aluminum-Butt Welds

Thickness, in.	*Passes*	*Current DCRP, amp.*	*Welding speed, ipm.*	*Rod diam., in.*	*Argon flow, cfh.*	*Joint preparation*
			Machine Welding			
$^1/_4$	1	330	48	$^5/_{32}$	35	Square butt
	2	330	48	$^5/_{32}$	35	Square butt
$^1/_2$	1	345	12	$^1/_8$	50	70° included angle, $^3/_{16}$ in. deep
	2	375	12	$^1/_8$	50	Back-chip 70° included angle, $^3/_{16}$ in. deep
$^3/_4$	1	470	12	$^1/_8$	60	70° included angle, $^3/_{16}$ in. deep
	2	470	12	$^1/_8$	60	Back-chip, same
$1^1/_2$	1	420	5	$^1/_8$	60	U-groove, $^1/_2$ in. deep
	2	435	4	$^1/_8$	60	2nd pass on 1st side
	3	435	4	$^1/_8$	60	Back-chip U-groove, $^1/_2$ in. deep

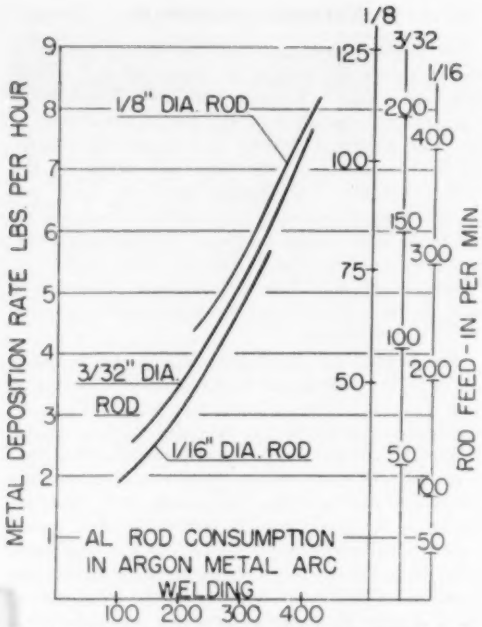

Fig. 3 Chart showing aluminum rod consumption in shielded inert gas metal arc welding

to 1215° F. is more prone to produce porosity than are some of the alloy compositions. It is general practice to weld aluminum alloys with a rod containing 5% silicon, and the balance aluminum in the solidification range of 1055 to 1155° F. Here porosity control is less of a problem. In some cases, particularly very heavy plate, it is necessary to preheat 2S to 300° F. to meet code requirements on X-ray examination.

Typical welding conditions for various thicknesses of 61S-T aluminum are illustrated in Table 1. These show some conditions which yield satisfactory results over a wide range of thicknesses. In general, welding conditions for 2S and 3S alloys are quite similar except that welding currents are higher or speeds are slightly lower. The chart in Fig. 3 shows the approximate metal deposition rate at various current levels with three sizes of welding rod. It also shows the approximate rate of welding rod feed speed in inches per minute which are used at the various current levels.

Fabrication of Vessels

Welded aluminum tank cars have been in use for a number of years principally for the transportation of acids. About five years ago, Heliarc welding replaced other methods of welding these tanks. This process was favored because of the freedom from flux problems and ease of training operators. Lacking a reasonably satisfactory mechanization of the Heliarc process, this work was all done by hand welding methods. Welding procedure was, for $^5/_8$-in. plate, generally as follows: plates were beveled to produce a 60° included angle welding vee with a $^1/_8$-in. nose. The joint was made using two passes in the vee and a third on the other side after back-chipping. The actual welding rate varied from 6 to 12 in. per minute. The net rate was, however, much lower due to stops because of operator fatigue and to change welding rod. The metal deposit rate amounted to about 3 lb. per hour under favorable conditions.

About two years ago shielded inert gas metal arc welding machines were introduced on this application. Later hand-welding units were added and now about 90% of the welding operations are performed by the shielded inert gas metal arc welding process. Depending on the service intended the shell thickness of these tanks varies from $^1/_2$ to $1^1/_8$ in. Plate composition is either 2S or 61S-T. In addition to the main shell and the dome assembly there is considerable welding connected with various nozzles, fittings, and anchor bars, and steam heating coils.

Operations at the General American Transportation Co., Sharon, Pa., illustrate the methods of using the shielded inert gas metal arc process in the construction of these tanks. After the sheets are rolled to shape and tack welded into a cylindrical assembly, they are welded by a shielded inert gas metal arc machine with one pass from the outside. The plates are prepared and assembled so that the 70° included angle vee is on the inside of the shell. The first pass weld from the inside is illustrated in Fig. 4. To facilitate rapid movement of

Fig. 4 Welding inside seam of a railroad car tank

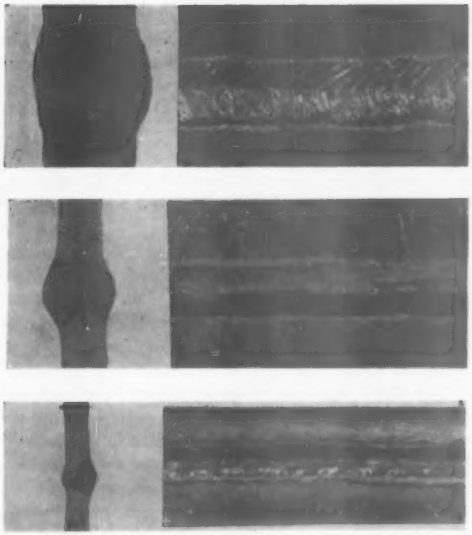

Fig. 5 Weld specimen 3/16 to 1/4 in. 61S-T

the equipment, the shielded inert gas metal arc welding head is mounted on a long fabricated beam which is, in turn, supported on a carriage mounted on rails, the weld is started at the end of the tank on end tabs which are visible in the foreground of this illustration. The second operation is to back-chip the longitudinal seams which on 3/4-in. plate is generally done to a depth of 1/4 to 3/8 in. The same machine is then used to complete the weld on the outside of the tank in one pass, making two passes for the 3/4-in. plate. A typical weld and section is shown at the top of Fig. 5.

After completing the longitudinal seams the heads are fitted. The thickness of the head is generally somewhat greater than the shell plate and the short straight section of the head is beveled so that the butting edges are equal in thickness. The outside seam between the head and the shell is first welded as illustrated in the foreground in Fig. 6. In the background a second shielded-inert-metal-arc welding machine is being used to weld the joint between the dome saddle and the top shell plate. This will be described in further detail later.

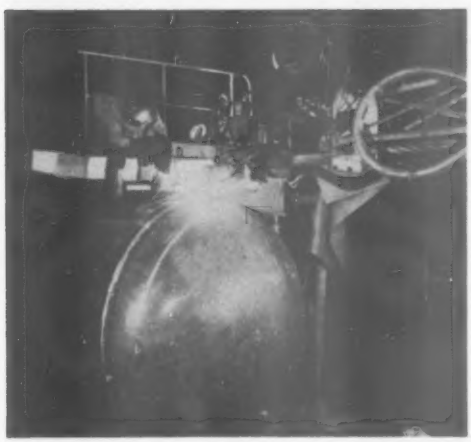

Fig. 6 Welded joint between head and shell of railroad car tank

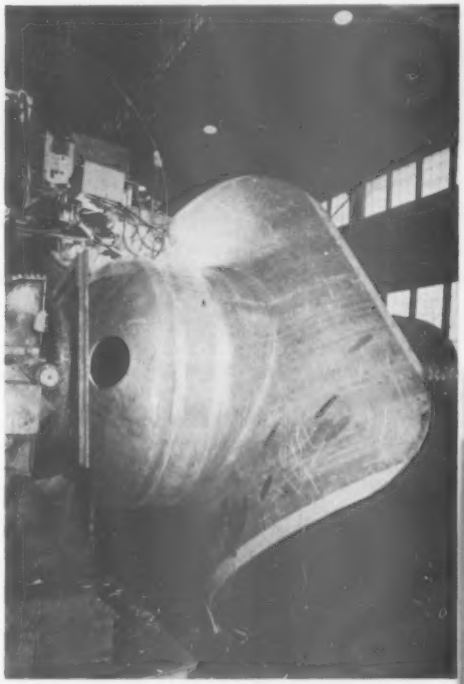

Fig. 7 Welding joint of dome assembly

The dome assembly which is generally of plate about 50% thicker than the shell plate, is prepared as a separate operation. It consists of three parts which are a forged saddle, a spun head and a short cylindrical section fabricated from plate. After tacking these three parts together, they are machine welded by the shielded inert gas metal arc process as illustrated in Fig. 7. The major weld is made from the outside as illustrated and a final pass is made on the inside. Satisfactory operations on this seam have been obtained with both machine and hand shielded inert gas metal arc welding equipment.

In general the same procedure is employed on these welds as on a tank shell, except that where the greater thickness requires, two passes are employed on the outside or beveled side. The dome assembly is welded into the top sheet of the tank as illustrated in the background of Fig. 6. The completed dome with filler connections installed is shown in Fig. 8. The completed butt weld between the saddle and the tank

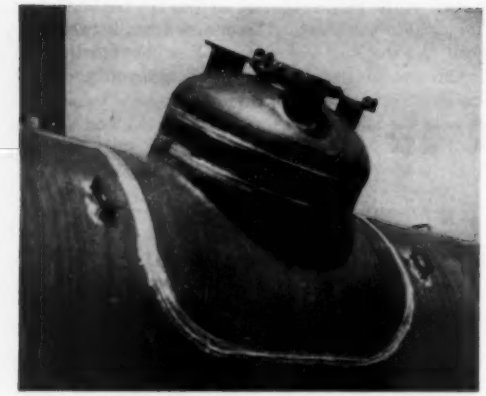

Fig. 8 View of completed railroad tank car dome assembly is shown

is shown as well as the manner in which the saddle plate is beveled to the same thickness as the shell plate at the weld joint.

Attached to the bottom of and extending approximately two-thirds of the length of the tank are two anchor bars machined from 1-in. thick extruded T sections. Since these are strictly structural members, the 61S-T composition is used for both the 2S and 61S-T tanks. These are attached by means of a continuous fillet on both sides of and extending the length of the anchor bars. The fillet also extends around the ends of the anchor bar. In some cases these bars are fillet welded in position using the large welding machine illustrated previously. In other cases they are attached by hand as illustrated in Fig. 9.

Attempts to use Heliarc welding in attaching these bars were generally unsatisfactory because of the high currents required to produce these large fillets. For the most part these bars were previously installed using flux-coated metal-arc aluminum electrodes. While generally satisfactory welds were obtained in this manner the time consumed to make the welds was excessive due principally to flux-removal operations. Although welding currents are not appreciably higher using the shielded inert gas metal arc welding hand torch, the over-all time to complete these welds is approximately one-half that required for flux-coated-metal-arc welding. More rapid operation with the shielded-inert-gas-metal-arc process is attributed to its more continuous character together with the elimination of flux removal. The completed welded anchor bars are shown in Fig. 10.

Upon the completion of welding of all seams in the tank, they are completely X-rayed and any defective areas found are chipped out and rewelded. Considering the thorough examination and the stringent requirements as to maximum allowable porosity as shown by X-ray, relatively little rewelding is necessary.

Very significant cost reductions have been achieved through the use of this mechanized process compared to previous hand methods. This is due to two factors. First, the completely mechanized character of shielded inert gas metal arc welding makes it possible to weld a complete 40-ft. longitudinal seam or a complete circumferential seam without stopping. This results in a high arc time compared to total time and greatly increases productive capacity of a given shop area. The second major factor is the metal deposition rate during arc "on" time. For seam welding of heavy plate this is about 7 to 8 lb. per hour. The major cost outside of labor in inert gas welding methods is the cost of gas. A significant ratio is, therefore, the gas cost per pound of metal deposited. For machine welding $^{1}/_{4}$-in.

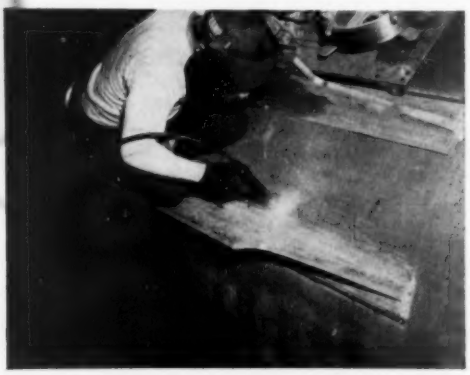

Fig. 9 Hand welding an anchor bar on tank

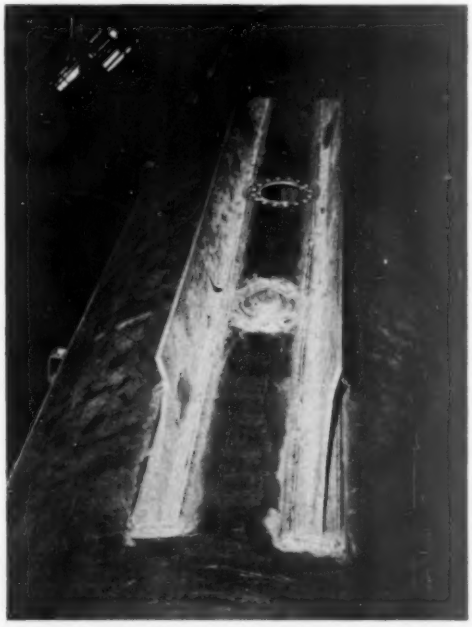

Fig. 10 Over-all view of welded anchor bars

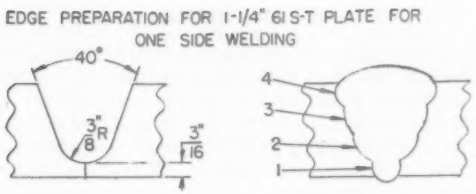

Fig. 11 Edge preparation for 1¼ in. 61S-T plate

Pass no.	*Current, amp.*	*Speed, ipm.*	*Rod size, in.*
1	230	18	3/32
2	340	10	1/8
3	400	5	1/8
4	400	5	1/8

aluminum plates, this is about $0.70 to $0.80, and for 3/4-in. plates about $0.55 to $0.65 per pound. Hand welding similar thicknesses in the flat position will entail gas costs about 20 to 25% higher for 1/4-in. plate and about 100% higher for 3/4-in. plate than for machine welding.

Machine welding of butt joints produces for each pound of filler rod 20 to 25 ft. of joint on 1/4-in. plate and 3 to 4 ft. on 3/4-in. plate. Hand-welding produces on 1/4-in. plate 10 to 12 ft. of weld for a pound of rod and on 3/4-in. plate about 2 to 3 ft. per pound of welding rod.

Special Joint Procedures

Where it is possible to weld from both sides, the methods illustrated in the foregoing sample are generally more satisfactory in that they will accommodate greater tolerance in fitup. This is due to the fact that the first bead is deposited in a relatively thick nose. In the manufacture of spherical vessels or other closed shapes where it is impossible to weld from the inside, a procedure has been developed allowing all of the work to be done from the outside and without a backup strip.

In the satisfactory application of this procedure on plates from 5/8 to 1 1/4 in. in thickness, it is essential that the nose section of the plate edges be butted as closely together as possible, but in no case with a clearance greater than 1/32 in. With the joint preparation and nose thickness as illustrated in Fig. 11, a first bead must be deposited at a relatively high rate as illustrated in the data. This will produce a completely fused and uniform drop-through with little danger of losing the weld through melting entirely through. The second pass is then installed at an intermediate rate—that is, adjusted to prevent burn-through of the relatively thin first pass. The bead is then filled with subsequent passes at the highest currents that are possible to use. Generally this limit is imposed by instability of the arc which occurs when welding currents much in excess of 400 amp. are employed. The top and bottom views of the completed weld are shown in Fig. 12.

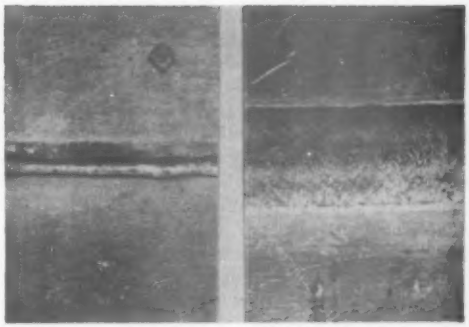

Fig. 12 One-side welds in 1¼ in. 61S-T plate

Fabrication of Structural Type Equipment

The discussion of the manufacture of railroad tank cars has served to illustrate the use of the shielded inert gas metal arc process in vessel manufacture involving relatively heavy plate. The process has also been used satisfactorily in the manufacture of aluminum dump truck bodies of 16 and 20 ton capacity. Aluminum construction in transportation equipment offers the opportunity to make major savings in dead weight. Several attempts have been made in the past to produce large dump truck bodies of aluminum using

Fig. 13 Seam welding aluminum dump truck body

riveted construction. While savings in the weight were effected, difficulties in manufacture and maintenance left much to be desired.

Several designs of welded truck bodies have been constructed and tested over a considerable period of time. It has become obvious that to attain low cost manufacture and durability in service, it is essential to employ a welding method easy to use, applicable to materials $^3/_{16}$ to $^1/_4$ in. in thickness, and a method that will result in a minimum of heat effect on the base metal was essential. These qualifications appear to be found in the shielded inert gas metal arc process which has been used in the fabrication of a large number of dump truck bodies. These bodies are fabricated from sheet and extruded sections tack welded into complete assembly and then seam welded. Since the plates and sections involved are relatively thin, and since a great deal of position and fillet welding is involved, and many of the seams are relatively short, the hand-welding type of equipment is most satisfactory for this work.

Figure 13 shows the hand-welding torch being employed on the seam joining the two $^1/_4$-in. thick bottom plates of a truck body. Notice the lack of sparks at the arc or spatter marks on the plate. Figure 14 shows a very convenient method for mounting the rod feed mechanism on the end of a small jib crane to allow it to be positioned readily within reach of any part of the body under construction.

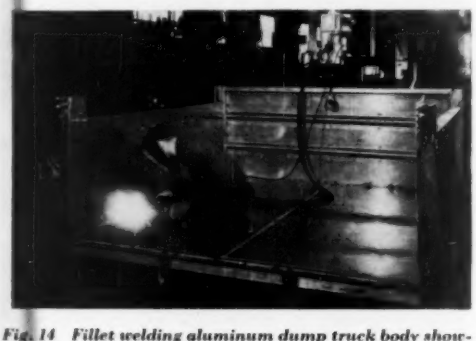

Fig. 14 Fillet welding aluminum dump truck body showing mounting of drive unit on jib crane

COPPER AND COPPER ALLOYS

The welding of deoxidized copper with freedom from porosity has long been a major problem in the metal fabrication industries. In recent years the use of Heliarc welding has allowed the fabrication of this material with extremely good dense welds. Likewise, the shielded inert gas metal arc process produces equally satisfactory results from a quality standpoint and with some distinct advantages from the cost aspect, especially in thick material.

In addition to producing a sound weld, satisfactory physical values of the weld joint are produced. In general, tensile strength of 30,000 to 33,000 psi. and an elongation of 42% in 2 in. may be expected. Some of the higher tensile values which are developed in deoxidized copper using the shielded inert gas metal arc process are due to the relative freedom from preheating requirements. In machine welding operations where high currents may be used, excellent welds are readily produced in materials up to and including $^1/_2$ in. in thickness without preheat. Table 2 lists typical operating conditions for machine welding deoxidized copper.

Silicon bronze, long popular for certain corrosive atmospheres requiring higher physical properties than pure copper, is another somewhat difficult-to-weld material which responds very readily to inert atmosphere welding procedures. In addition to some difficulty in securing sound welds, this material under some conditions is difficult to handle because of hot-short cracking characteristics. The use of a relatively large number of small beads has been found effective in overcoming this difficulty in Heliarc welding. The shielded inert gas metal arc process is well adapted to this type of operation and the production of crack-free welds under conditions of high stress is readily accomplished.

Typical physical values that might be expected are, as determined by reduced section tensile tests, as follows: yield point, 18,000 to 19,000 psi.; ultimate strength, 54,000 to 57,000 psi.; elongation of 40 to 50% in 2 in.

An important application of aluminum bronze is that for low-temperature service. Impact strength as measured by Charpy tests on 10- x 10-mm. specimens in and adjacent to the weld zone indicates the shielded

Table 2—Shielded Inert Gas Metal Arc Welding Process Conditions for Deoxidized Copper

Plate thickness, in.	*Pass*	*Current amp., DCRP*	*Welding speed, ipm.*	*Rod* diam., in.*	*Rod feed speed, ipm.*	*Argon flow, cfh.*	*Edge preparation*
$^1/_8$	1†	310	30	$^1/_{16}$	200	35	Square butt
$^1/_4$	1	460	20	$^3/_{32}$	135	35	Square butt
	2	500	20	$^3/_{32}$	150	35	Square butt
$^3/_8$	1	500	15	$^3/_{32}$	150	35	90° vee included angle, $^3/_{32}$ in. deep
	2	550	14	$^3/_{32}$	170	35	90° vee included angle, $^3/_{32}$ in. deep
$^1/_2$	1	540	12	$^3/_{32}$	165	35	90° vee included angle, $^1/_8$ in. deep
	2	600	10	$^3/_{32}$	180	35	90° vee included angle, $^1/_8$ in. deep

* Nominal composition of rod, silicon 0.25%, tin 0.75%, manganese 0.15%, balance copper.
† Steel backup used.

inert gas metal arc process will produce readings of 35 to 40 ft.-lb. at room temperature, and 30 to 35 ft.-lb. at minus 300° F. These compare well with the results obtained by Heliarc welding.

ALUMINUM BUILD-UP OPERATIONS

In addition to straight fusion welding applications, the shielded inert gas metal arc process has been found very useful for build-up operations in the repair of aluminum Diesel engine pistons. The ability to deposit large amounts of metal under controlled welding conditions produces dense deposited metal at reasonable cost. Several compositions are used which contain some or all of the following elements: copper, iron, manganese, magnesium, silicon, zinc, aluminum or nickel.

These compositions make it possible to produce a lightweight, strong piston with good wearing qualities. However, the high temperature and pressures encountered result in eventual wear and erosion. Replacement of the piston usually occurs when erosion by hot gases damages the piston head and in some cases cuts a channel around the piston rings.

Three worn pistons that have been machined ready for welding are illustrated in Fig. 15. Eroded areas on the sides of the two larger pistons in the background are visible. The piston on the left has had the ring grooves enlarged by machining to clean up the surface of the metal to be welded. The large piston on the right has been machined in such a manner that several of the ring grooves have been eliminated to form three large channels that will be filled with weld metal. A similar treatment has been accorded the smaller piston in the foreground.

The following procedure is suggested in the rebuilding of worn pistons. First, all worn areas requiring filling, including the ring grooves, should be machined to sound metal. Second, the piston should be completely degreased and then placed in a rotating welding fixture in position for welding. The piston should then be preheated to a temperature range of 200 to 300° F. and welding started immediately. Buildup of the major areas in the vicinity of the grooves is done as a continuous operation using a welding machine similar to that illustrated in Fig. 2. A large engine lathe makes an ideal fixture, because the welding head can be traversed along the piston as the beads of filler metal are deposited. In general, a traverse of about $^1/_2$ in. per revolution is satisfactory.

Fig. 15 Worn aluminum pistons

The electronic arc length control is of great value in this type of operation to obtain satisfactory penetration at the edges of the built-up area where the deposited metal is to be fused in with the sides of the machined-out areas. Adequate penetration is ensured by lowering the arc voltage one or two volts while the bead is deposited in the corner. An increase in the arc length while traversing in the center portion of the built-up area serves to increase the width and flatness of the deposited bead.

Fig. 16 Pistons repaired by machine shielded inert gas metal arc welding

Figure 16 shows the same three pistons after welded repair. Note the continuous spiral bead around the upper portion of the piston in the ring groove area. While the length of time required to build up any particular piston will depend upon the size of piston and amount of defective area to be replaced, production records show that for a $12^5/_8$-in. diameter piston 10 lb. of 5% silicon alloy rod can be deposited on a piston in approximately 45 min. arc time. This requires 45 cu. ft. of argon. Because the spatter rate is extremely small and the spatter that does occur does not adhere tenaciously, it is unnecessary to apply antispatter paint to the piston. It is also unnecessary to stop the operation during the course of the weld to remove spatter from the cup. The welding operation is uniform and continuous, one layer of bead being deposited on the other until the cavity is completely filled to the

Fig. 17 Piston repaired by hand and machine shielded inert gas metal arc welding

desired height. About the only reason for stopping the operation during the course of welding is to refill the rod reel. This is cut to a minimum by the use of 50-lb. coils of rod.

Upon completion of the welding operation, the pistons are slow cooled under an asbestos blanket. Measurements have been made to determine the distortion resulting from the welding operation. These show that resultant maximum "out-of-roundness" is very slight and in some cases less than that resulting from wear by the time the piston is resurfaced. Change in size of wrist-pin holes may be expected. In general, the change will be an increase in diameter of between 0.001 and 0.002 in.

Cavities sometimes occur in the top of the piston head, due to erosion by the hot products of combustion. Figure 17 illustrates a piston in which several such cavities in the head were repaired by hand welding.

SURFACING OPERATIONS

The repair of Diesel engine pistons illustrates the method of depositing materials similar in composition to the base metal. An allied type of operation, but for a different purpose, is that of depositing special alloy compositions to impart corrosion and wear resistance. The usual hard-facing and stainless steel and other coating operations are in this type of work. The shielded inert gas metal arc process shows promise of being extremely effective in many of these operations.

Although for welding, the good penetration characteristic of the inert gas arc is highly desirable, on surfacing operations such a characteristic must be overcome. It is important that admixture of the surfacing material with the base metal be held to a minimum for several reasons. The most important of these is that admixture with the base metal may lower the corrosion or wear resistance of the coating material. It may introduce serious cracking problems, or in other cases may create hard spots interfering with later machining operations. Success has been obtained in limiting penetration in the case of aluminum bronze deposits on carbon steel to a depth of about 0.015 in.

Two common services for which a copper alloy coating on steel is desirable are for wear resistance in valve seat surfacing and for connection seating surfaces in lead lined vessels. In the case of valve seats, the relatively tough wear-resistant aluminum bronze compositions are found desirable. To provide a sufficiently firm seat for gasket faces that has good corrosion resistance to match that of a lead lined tank, either aluminum bronze or silicon bronze may be used. Both of these bronze compositions are readily applied to steel using the shielded inert gas metal arc process with either hand- or machine-type equipment. Generally, ductility of the deposited metal is very satisfactory. For some special cases, where this is not so, increased ductility or resistance to impact may be obtained by interposing a layer of very ductile material between the steel and the final coating. In the case of copper alloy compositions, pure copper itself may be used for this purpose. Figure 18 shows a section cut from a $^1/_2$-in. steel plate on which a $^1/_4$-in. layer of aluminum bronze (92% copper, 8% aluminum) was deposited. The surface and edges have been machined and a sample bent with the coating layer in tension. Ductility measured in similar tests showed 35% elongation without cracking. The low degree of penetration into the base metal and the lack of porosity will be noted in this photograph. Because of the relatively

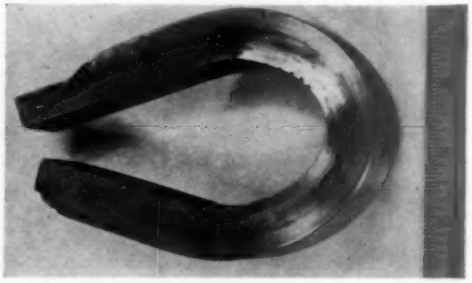

Fig. 18 Aluminum bronze deposit on $^1/_2$-in. steel plate

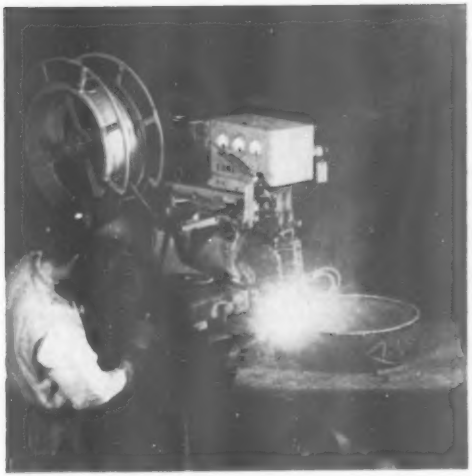

Fig. 19 Aluminum bronze deposit on valve seat ring

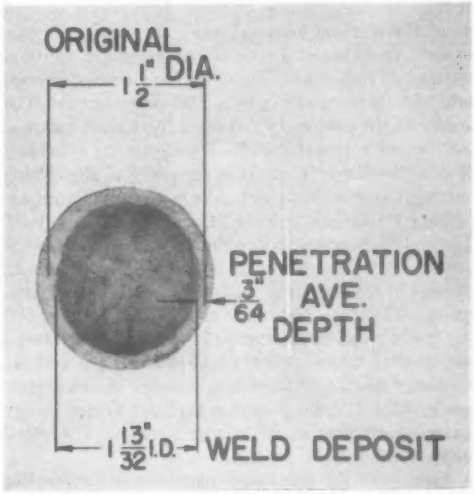

Fig. 20 Hastelloy alloy C deposit on carbon steel shaft

viscous character of some aluminum bronze compositions, it is possible to build up relatively high and narrow deposits by the multiple bead technique. This is particularly useful in surfacing relatively narrow edge as in the case shown in Fig. 19. This is a seating ring for a large valve. Here $^1/_8$-in. aluminum bronze rod is deposited at a travel rate of 40 in. per minute, using 400-amp. direct current, reverse polarity, and building up approximately $^3/_{32}$ in. per pass.

Another common type of facing operation is that of coating or building up piston rods and other steel sections with wear and corrosion-resistant surfaces. In some cases these deposits are stainless steel and for more rigorous service "Hastelloy" alloy C is frequently used. Here by proper manipulation of the arc, it is possible to deposit the coating material at a rate of about 5 lb. per hour on relatively small diameter shafts. On larger shafts where larger puddles and higher currents can be employed, higher deposition rates are possible. A cross section of a $1^1/_2$-in. diameter shaft coated with Hastelloy alloy C is shown in Fig. 20. Here the average penetration is approximately $^3/_{64}$ in. on the first pass. Coating two layers assures virtually pure coating material on the final wearing surfaces.

CARBON STEEL

The welding of carbon steel by the inert gas tungsten arc method has never been too successful in thicknesses in excess of $^1/_8$ in. because of formation of gross porosity. It is thought that this formation of porosity is a function of time during which the metal is held in the fluid state. Extensive testing of methods of welding carbon steel by the shielded inert gas metal arc process has shown that by proper use of the high heat input rate available a considerable control can be exercised over the molten metal. By suitable control through joint preparation, speed of welding, bead technique and gas protection, porosity in several grades of killed and rimmed carbon steel has been effectively controlled. Welding rod composition also is of considerable importance in obtaining commercial quality welds. Deoxidized steel is required and the deoxidizer system must be carefully established and controlled. Because of the lack of suitable welding rod in commercial quantities no significant applications of the process have been made on carbon steel materials.

In comparison with other established methods of welding carbon steel, there is a question concerning the cost of the relatively expensive shielding gas employed in shielded inert gas metal arc welding. Because of the lack of production experience, it is difficult to judge what significance this new process will have in the carbon-steel welding field. It should be interesting, however, to discuss the factors involved. Well-established production operations with the Heliarc process have shown the unique advantages of inert-gas welding, in the over-all picture, to offset the cost of the gas for certain applications. Excellent control of quality is obtained in Heliarc welding on sheet steel thinner than $^1/_8$ in. Where freedom from flux, control of weld buildup, low distortion and high welding speeds are essential, the Heliarc process finds extensive use as in the automotive field.

The shielded inert gas metal arc process is also free of flux and has possibilities of high welding speed. It does not, however, have the same easy control of weld buildup available in the Heliarc process. Furthermore, the consumed welding rod required becomes very small when welding thin material in the gage thicknesses. It, therefore, seems that any major carbon steel field of application that might exist for the shielded inert gas metal arc process will be in the welding of material of about $^1/_8$ in. in thickness and

above. In the welding of these thicknesses of material, the shielded inert gas metal arc process appears to have two characteristics of importance in addition to freedom from flux. These are: high metal deposit rate and the availability of a high duty factor. The ability of the process to satisfactorily deposit metal at high rates stems from the excellence of shielding afforded by the inert gas plus the mode of introducing current to the welding rod. As in the submerged arc process, continuous welding rod is supplied from coils. The welding current is introduced to the rod near the arc, so that the amount of resistance heating due to passage of the current through the rod is held to a minimum. Thus for a given size of rod much higher welding currents can be employed than for flux coated metal arc welding where short lengths of welding rod are normally used. As an example, using shielded inert gas metal arc $^1/_4$-in. plate can be hand welded in two passes, each pass at 30 in. per minute. The metal deposit rate is 13 lb. per hour.

Because of the continuous character of the welding rod, the length of "arc on" time may be as long as suits the convenience or comfort of the welder. When the arc is broken before completion of a weld, it may be restruck without further preparation such as flux or slag removal from the crater. Comparative tests have indicated that under conditions where the operating factor for flux coated metal arc welding is 35% the shielded inert gas metal arc process should allow an operating factor of 60 to 65% with equal ease. Obviously only certain types of high production welding operation can take advantage of such a high operating factor that is possible. Where, however, such conditions do exist, it appears that hand welding by the shielded inert gas metal arc process should produce completed welds at a rate of from three to six times the rate possible with flux-coated metal-arc welding using, where possible, the "hot rod" technique for the latter.

Since the shielded inert gas metal arc process requires 35 to 50 cu. ft. per hour of shielding gas when depositing weld metal at the rate of 10 to 20 lb. per hour the argon consumption is in the neighborhood of 3 cu. ft. per pound of metal. The cost of this gas as a material charge does not have a counterpart in the flux-coated metal-arc process. If the shielded inert gas metal arc process is to be competitive this gas cost must be offset by higher production per hour of labor and overhead. On high production, repetitive types of operations, it seems reasonably certain that these conditions will be met.

An anticipated advantage of the shielded inert gas metal arc process is the low degree of spatter. This, in some cases, may be significant from a cost of cleanup standpoint. In all cases, however, it results in higher metal recovery rate. The metal in the final weld, expressed as a per cent of the welding rod used, is about 98% for the shielded inert gas metal arc process, while for the flux-coated metal-arc process it is about 65%. While this is a substantial difference, it is possible that the cost of welding rod for the shielded inert gas metal arc process will be sufficiently higher per pound so that the final welding-rod cost will be about the same.

STAINLESS STEEL

As in the Heliarc process, the shielded inert gas metal arc process allows the deposition of most of the stainless steel alloys of the SAE 300 series with little or no alloy loss. In those cases where weld metal composition, the same as base, is satisfactory from a service standpoint, a rod of the same composition as the base metal may be used. This results in some economy and simplification in selection of the welding rod to be used. Where service conditions such as for low-temperature impact require a weld deposit of higher alloy content, filler metal selection may be readily made with the knowledge that no significant alloy loss will be encountered.

Metal deposit rates obtained with welding of stainless steel by the shielded inert gas metal arc process are similar to those shown above for carbon steel. In the case of stainless steels, however, somewhat lower argon flows may be used. The hourly consumption found satisfactory in experimental work varies from 20 to 40 cu. ft. per hour or about 2 cu. ft. per pound of metal deposited. Because of the higher electrical resistance of stainless steel alloys and flux loss problem, relatively lower maximum currents must be used when welding these metals with flux-coated rods than is the case for carbon steel. Therefore, the comparison of the two processes is more favorable to the shielded inert gas metal arc process from the standpoint of labor costs when welding stainless steels than when welding plain low-carbon steels.

As in carbon steel welding, spatter losses are about 2% when welding stainless steel with the shielded inert gas metal arc process, and about 35% weight loss with the flux-coated rod process. However, in the case of stainless steel the relatively higher costs of filler rod make the high rod recovery rate of the shielded inert gas metal arc process a matter of considerable economic importance.

The savings due to better metal recovery with the shielded inert gas metal arc process amount to about 30% of total rod cost. At a metal deposit rate of 10 lb. per hour and an assumed rod cost of $1.00 per pound, this amounts to a $3.00 saving per hour. This is equal to or greater than the cost of the 20 to 25 cu. ft. of argon required for the shielded inert gas metal arc process. Thus, in some cases, the saving due to better rod recovery will offset the cost of the argon consumed.

Duty factor in stainless steel welding with the shielded inert gas metal arc process should be well above that obtainable with the flux-coated process. The difference is, however, that the economy of using the newer process depends to a small extent, if any, on the attainment of high operating factor when welding stainless steel alloys.

CONCLUSION

The shielded inert gas metal arc process is a rapid means of joining a wide variety of metals and alloys. It combines well-known advantages of inert atmosphere shielding with a highly concentrated heat transfer medium. While the arc exhibits good penetrating characteristics generally desirable for joining operations, application of suitable technique results in a low degree of penetration required for surfacing and hard-facing operations. Control of dilution, combined with the inert atmosphere which prevents alloy losses, results in extreme flexibility in choice of surfacing material and base metal composition.

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Quality Control of Structural Resistance Welding in Aircraft

The basic standards for quality and procedures are outlined in the current military specifications for spot and seam welding of aircraft materials which can be modified to suit the facilities and requirements of an individual factory

by J. R. Fullerton

AS NEW developments in equipment and techniques of control increase the quality of resistance welding, spot and seam welding are finding ever-increasing use as a method for joining structural aircraft components. This increased use is demanding more efficient and rigid controls to insure quality production joints.

The basic standards for quality and procedures are outlined in the current military specifications covering the spot and seam welding of aircraft materials. We have found that the requirements of these specifications provide a good basic standard, but that it is necessary to require additional checks and controls which are dependent upon the individual factory, equipment, procedures and personnel involved.

The complete control of the spot- and seam-welding process is based upon the ability of the machine to duplicate results under controlled conditions. It is this characteristic of duplication and the control of the conditions under which the machines operate which are the greatest concern in quality control. Therefore, it is apparent that quality control will involve many separate factors and departments.

PERSONNEL

Securing adequately trained personnel and utilizing their skills most efficiently is one of the greatest problems. The personnel problem includes all individual departments involved in the fabrication of the finished part from its design to its final acceptance. Since there are many different problems involved in design, fabrication, inspection, maintenance and welding, it is apparent that it is impossible to have in each function a person with a complete knowledge of the resistance welding process and its associated problems. Therefore, to achieve quality finished parts the efforts of all of the people concerned must be coordinated toward the common goal of making sound, consistent joints. We accomplish this task at Ryan by making available to all of our personnel concerned with parts to be spot or seam welded, our complete laboratory facilities for consultation and assistance on the problems involved. This effectively makes our most highly trained technical people available where needed whether the problem be chemical, metallurgical, electrical, welding, fabrication or any combination of the above. We feel that this arrangement provides us the maximum utility of our more highly skilled technical people and that with consultation and assistance readily available, the people whose work involves only a small portion of the resistance welding problems can be readily trained to handle the routine work. Experience has shown that it is also desirable to keep the control of the welding process vested in as few people as possible so that problems may be quickly and efficiently handled by personnel directly connected with the problem. Our process is jointly controlled by the Laboratory and Inspection Departments. The

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Laboratory conducts the necessary tests and establishes the procedures and settings while the Inspection Department conducts the routine production tests, coordinates processes with customer inspection and generally polices the process. This arrangement effectively places the responsibility for the process on two people, the Resistance Welding Supervisor of Inspection and the Welding Engineer of the Laboratory. This has worked quite well in our structural welding process since it permits immediate attention to any problem by capable personnel.

MAINTENANCE OF EQUIPMENT

Maintenance of equipment plays an important role in structural welding. The machines must be maintained in such good condition and calibration that any qualified setting may be used and results obtained equal to those obtained on the original certification tests. Equipment required for maintenance of different types machines will vary slightly. Maintenance instruments which we feel are indispensable in our program are:

1. Tip pressure gage—(0–5000#).
2. Oscillographic equipment (direct inking preferred).
3. Oscilloscope.
4. Tube tester (receiving type tubes).
5. Tube tester (Ryan design for special tubes).
6. Millivoltmeter—d. c.
7. Strain gage equipment.
8. Stop pointer meters (voltage and current).
9. Clamp on transformers, voltage dividers and accessory equipment.
10. Cycle counter.
11. Vacuum tube voltmeter.
12. Volt-ohm-milliampere Meter.

Also available to the maintenance man should be a complete file of manufacturers' literature on specific tests and adjustments on equipment involved. We have found that it is a great assistance to keep data on different machines regarding symptoms as a help in making rapid repairs. These data include symptoms, date, checks made, location and repair of trouble. This system enables us to locate troubles faster and localize specific problems in each type machine. It also indicates where a design change to the machine may be necessary to rectify troubles encountered too frequently. As a result of this system, we have occasionally made small changes in equipment. Another practice which we have found profitable in maintenance is the measurement and logging of critical voltages on different types of controls to expedite maintenance checks and repairs. We have found that in addition to repairing malfunctions or breakdowns in production, that it is a good policy to make periodic checks on our equipment. These checks are made weekly, monthly and annually in our plant. The weekly check is basically an operational tightening up and lubrication check with additional adjustments and repairs made as needed. The monthly check is more comprehensive and includes oscillographic checks for timing, pressure, consistency, secondary joints and operational calibration. The annual check is very thorough and includes cleaning of secondary joints, testing of tubes, cleaning of cooling system and is effectively a complete overhaul. These maintenance activities may seem excessive to many but we feel that since the maintenance of the machine and its accessories is such an important part of structural welding it must be as well controlled and checked as possible. These problems require skilled mechanical, electrical and electronic maintenance personnel. Men of this caliber are relatively hard to find. To cope with this problem we have recognized this extra skill requirement and have a job classification with a premium rate for maintenance electricians doing this type of work. Since recognizing this extra skill it is interesting to note that our repairs are being made more rapidly and the quality of our welding machine maintenance is improving.

THE OPERATOR AND INSPECTOR

The welding machine operator is another great factor in quality control of resistance welding. Regardless of condition of machine, establishment of settings, inspection surveillance and assembly of parts, it is he and he alone who makes the weld. He must be familiar with the job and be conscientious in his work. He must be properly trained in resistance welding and know the type of equipment he is operating, the type of material he is welding and be well aware of their characteristics and handling qualities. These operators are not generally available and it is common practice to train them on the job. In controlling this problem we have new personnel trained by more experienced people who use them as helpers. As their training and knowledge permit, we reclassify them as operators. When a man becomes an operator it is still not practical to depend entirely upon his judgment as to quality. It is necessary to control the process by check and recheck. At this point the Inspector comes into the picture. Spot-weld inspectors, like operators, are not normally available and must be trained under experienced spot-weld inspectors. The work of each of these men also comes under the surveillance and spot check of the floor supervisory people who have had extensive experience in the resistance welding process.

With this system in mind we start on the control of the process in the shop. The production setup is established by the Laboratory who set the standard which inspection must maintain. The data for the production procedure is on the certification sheet attached to the machine. These data provide the operator with the settings to do the job. The operator sets the machine to the settings called out on the certification data sheets for the gage combination involved. Samples are prepared for the Inspector to test as required by specification. The Inspector then checks the machine setup for conformance with the data sheets.

The tests are run and the results compared with those obtained on the certification test; if results of inspection tests are satisfactory production begins; if results are not satisfactory, the machine settings are adjusted within ±10% on heat setting and new setup tests are run. If it is impossible to make satisfactory settings within ±10% tolerance on heat, maintenance is called to repair the machine.

FABRICATION TECHNIQUE

Fabrication and handling techniques are very important in the quality control of welding processes. Surface condition of steels and the super alloys generally are not too critical and usually may be welded without special preparation. It is well to avoid sandblasted parts, or parts which have been tumbled or burnished with aluminum oxide, however. We find the pickled or polished material most satisfactory. Aluminum alloys present special cleaning problems which exist in every factory. The surfaces to be welded must be cleaned chemically and a uniform etch applied to perform satisfactory resistance welding. It is necessary to alkaline clean and etch each part and control the handling very carefully to achieve success in this process. As a control of this cleaning, we use surface resistance as an index of cleaning efficiency. Maximum permissible surface resistance in our process is 50 micro-ohms with normal resistance of approximately 20 micro-ohms. It is interesting to note at this point that while surface resistance is a good indication it is not a guarantee of spot weldability. We have found in our process that some alkaline cleaners permit silicon carry-over which does not show on surface resistance tests, but is easily detected in routine X-ray tests or by reduced tip life. This silicon carry-over causes splitting and small radial cracks. To control this problem we have selected our cleaner and etchant solutions only after extensive testing. We control them by routine daily tests by our chemical laboratory. Tests on these cleaning solutions include chemical and temperature checks daily and surface-resistance checks at the beginning, middle and end of each shift. The results of these tests are logged daily. If these tests are not satisfactory, the process is stopped until the problem is solved.

Fit of parts is quite critical in structural spot and seam welding. Parts must fit so that they may be brought into contact with light manual pressure at each point a weld is to be made. This requirement is often taken lightly, yet it affects the quality of the welded joint more than most people realize. Any deviation from this requirement will cause a change in the weld characteristics and/or a tension stress concentration in the nugget area. Either of these conditions is not acceptable in structural welding. If the pressure of the welding machine is used to form the parts, the net electrode force on the joint is changed and the weld will not be in conformance with the certification. Tension loading of a spot or seam weld in parts not properly fitted may cause premature failure of the assembly.

Positioning of work in the welding machine is often critical and has a definite effect upon quality. In recognizing this it is easy to see that handling fixtures, jigs, counterbalances and other such aids should be utilized where possible to reduce operator fatigue.

Tip materials and geometry are specified on the certification data sheet and must be checked regularly. To control this we metal stamp electrodes with alloy designation and supply personnel concerned with a tip radius gage. These gages were not readily available so we designed and built our own as have most companies who wish to check radii in excess of $^1/_2$ in. The gage we have found most suitable is made from 0.020 in. "feeler stock" $^1/_2$ x 8 in. with the desired radii ground into them. Tip size and radii are checked by inspection at each setup and hourly on each routine check, or more often when parts being welded require sharp radii which are difficult to maintain.

Experience has shown us that the general recommendations of the manufacturers of resistance-welding equipment are rather light on pressure requirements and that in developing structural welding schedules we are tending toward higher pressures and larger nuggets to insure sound production welds.

In structural seam welding our experience has been that we must check spacing carefully on both aluminum and steel. It is apparent that more rigid quality welding requirements will reduce the speed of continuous drive on seam welders. This indicates the necessity for intermittent drive with rapid indexing features on production machines of the future.

Another requirement we make on critical structural assemblies is that of having each operator identify the assemblies he has welded with a rubber stamp. This helps our quality in two ways. First is the inherent pride in workmanship which is built into an assembly which a man stamps off personally. Second, the stamp provides a check on operators whose work is substandard so that they may be further instructed or reprimanded as necessary.

All of the above checks and utilization of skills are necessary in making sure that the welded joints will function satisfactorily, but we have not yet reached what we call "quality control." In making the necessary physical checks and cross checks and utilizing coordination and experience we have overlooked one major factor, the human element. This factor is also important in quality control. Therefore, when we can comply with the physical requirements and subdue the "good enough" attitude by developing pride in good workmanship, we come to the Inspector placing the final acceptance stamp on the welded part. When this Inspector and the workmen ahead of him finish their operations and can say to themselves "that part is as good or better than the designer planned it," we have what I would call "quality control."

Design Data for Brazing—Part III

The material presented is design data recommended by the Welding Section of the Schenectady Works Lab. and is being used by Design Engineers within the General Electric Co.

by W. J. VanNatten

III. BASIC DESIGN OF JOINTS FOR BRAZING

THERE are three principal types of joints used in brazing: Lap or shear, scarf and butt, each of which may be used with flat, round or tabular members.

As noted under "Base Materials," Section I, it is important to consider the effect of thermal expansions and contraction in designing for brazing where unlike metals are to be joined.

A. Lap Joints (Fig. 1)

Lap or shear type joints are the most reliable, simple and easy to braze and joints should be designed for shear wherever possible. Moreover, lap joints give a better opportunity to support the members properly and maintain correct clearances. From an electrical standpoint, lap joints offer joints whose electrical resistance is no greater than that of the lightest member of the joint.

The lengths of lap (depth of shear) will vary according to the thickness, strength of the metals being joined and the factor of safety wanted. It is evident that the large number of factors which affect the strength of a brazed joint makes it very difficult to give a precise formula for determining the length of a lap or shear joint for some required strength. For the sake of calculating designs, the following values can be used as a basis.

Flat Shear Joints

This formula applies only to lap joints which distribute the load over the whole area.

X = (unknown) = length of lap (shear).
T = tensile strength of weakest member (it is best to use the value of the annealed condition of the base metal).

W. J. VanNatten, Welding Section, Schenectady Works Lab., General Electric Co.

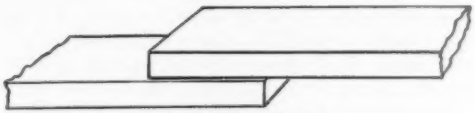

Fig. 1 Lap joints

W = thickness of weakest member.
Y = factor of safety.
L = shear strength of brazing alloy (use minimum values given in Section II. If not specified in Section II then use 30,000. This only applies to copper and silver alloy filler metals).
$X = YTW/L$.

Example: What length of lap should be (used when brazing a piece of low-carbon steel 0.125 in. thick × 1 in. wide to a piece of deoxidized copper 0.125 in. thick × 1 in. wide using B1 brazing alloy).

T = 33,000 psi. (T. S. Copper in annealed condition).
W = 0.125 in.
Y = 5 (NOTE: Where shear depths are limited a smaller safety factor is permissible).
L = 38,000 psi. (taken from Section IIB for B1 brazing alloy).

Then

$$X = \frac{5 \times 33{,}000 \times 0.125}{38{,}000} = 0.54 \text{ in.}$$

In electrical design a rule-of-thumb method of lapping the parts $1^1/_2$ times the thickness of the lightest member has been used extensively with good results. However, for convenience it is often desirable to use a longer lap.

B. Scarf-Butt Joints

A scarfed-butt joint is little stronger than a square-butt joint, but is more ductile. The electrical conductivity is also somewhat greater than the square-butt joint.

Two types of scarfed joints are used. The most commonly used type (see Fig. 2 (*A*)) is made with the scarfed surface forming an angle with the flat of the conductor strip. The scarfed dimension usually forms

Fig. 2 Scarf-butt joints

a lap equal to the thickness of the strip when the thickness of the strip is $^1/_8$ in. and under. With heavier strips the angle is made sharper, so that the lap is two, and in some cases, three times the thickness.

The other type of scarfed joint is made by the scarfed surface forming an angle with the edge of the conductor strip (see Fig. 2 (*B*)). This type of scarfed joint is more difficult to make, but is of particular advantage when winding strips are bent or formed on edge.

C. Straight- or Square-Butt Joints

It is always desirable to avoid butt joints of any design wherever possible but where strips have to be joined without increasing the cross-sectional area then butt joints must be used (Fig. 3).

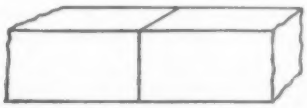

Fig. 3 Straight or square butt joints

With straight- or square-butt joints the members to be jointed are squared so that both members have their cross-section areas in complete contact.

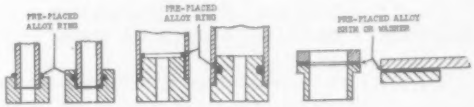

Figure 5

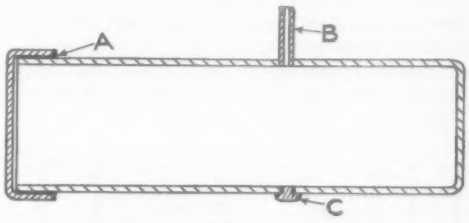

Figure 6

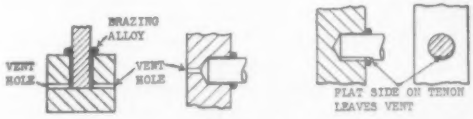

Figure 7

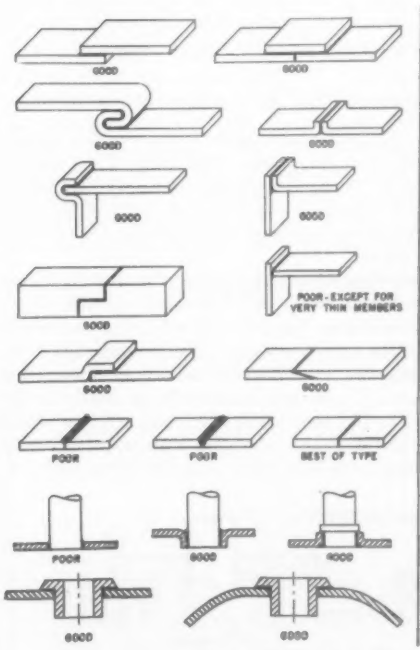

Fig. 4 Illustrations of joints

The proper squaring of the joint members is a simple operation but on wide strips and where the joints have to be of the highest quality, it is sometimes necessary to use squaring blocks.

As a definite rule, square-butt joints add electrical resistance in the circuit—therefore it is necessary to use a brazing alloy having the highest conductivity with the greatest ductility. For such applications B4(a) brazing alloy (see Section IIB) is recommended.

D. Illustrations of Joints (Fig. 4)

1. Preplacing of Brazing Alloy

Where brazing alloys can be preplaced in position, there are a number of advantages, such as:

(*a*) The flowing of the alloy automatically indicates the proper brazing temperature.

(*b*) The amount of brazing alloy per joint can be predetermined and the cost controlled.

(c) It insures the homogeneous filling of the entire joint area.

2. Venting of Closed Containers and Hollow Bodies

Closed containers and hollow bodies should be properly vented to get the best results in the brazing process (Fig. 5).

The heat from the brazing operation expands the air or gases in the container so rapidly that unless the assemblies are well vented or firmly locked together, the members are likely to be forced apart and at the same time forces act on the joint which tend to minimize capillary attraction.

Containers which are to be ultimately leak tight or vacuum tight may be designed as in the following example:

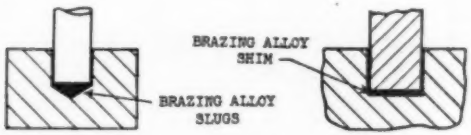

Figure 8

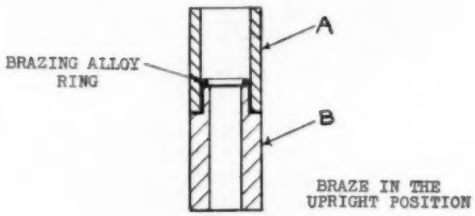

Figure 9

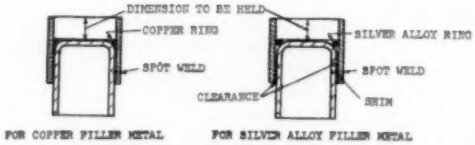

Fig. 10 Spot weld to prevent slipping

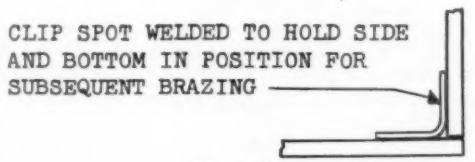

Figure 11

The brazing of a joint such as one end of a container *A*, may be accomplished by drilling a small hole in another part of the container. This allows expanding gases in the container to escape during the brazing cycle (Fig. 6).

The small hole then may be closed in a number of ways:

1. If the container is to be filled with a liquid a small tube, *B*, may be jointed to the container previous to brazing the end. Then the tube may be closed off by soldering or welding after filling the container. The soldering or welding is done easily because there is a very small joint area to be heated and therefore very little gas comes in contact with the area being heated.
2. If a tube is objectionable then a small slug, *C*, may be soldered or welded in place to form a leak-tight or vacuum-tight container.
3. In some cases filling the hole with solder may be sufficient for the application.

When a tenon is inserted in a dead-end hole, as illustrated in Fig. 7, the hollow space at the end of the tenon sometimes must be vented. Venting these parts reduces the chance of blowing the members apart during the brazing cycle. Different ways of venting are illustrated in Fig. 7.

In cases where the part or assembly cannot be vented then provision may be made, in certain applications, so that the alloy can flow from the inside of the part through the joint to the outside as the following figures show. However it is usually necessary to add pressure to the parts to aid the alloy in flowing through the joint as well as keeping the parts from blowing apart (Fig. 8).

3. Supporting Parts and Assemblies During Brazing

It is very important that parts or assemblies are supported so that the proper relationship of the parts is maintained during the brazing cycle. The method of holding the assemblies together, the design of the joints and the means of applying the brazing alloy are all very closely related.

Even before the proper method of supporting a joint is considered it would be well to remember one important phenomenon having a direct bearing on brazing, namely, the force of gravity. The brazing alloy naturally tends to flow downward more than in any other direction. It will creep horizontally or upward on the surfaces of the base metal, but it will also flow downward quite freely and will collect at low spots especially if an excess of brazing alloy is applied to the joint. It

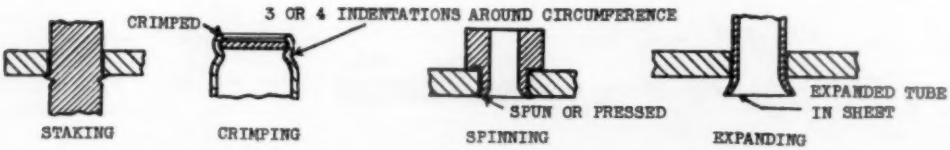

Figure 12

is realized that the brazing of all parts cannot be accomplished in an upright position with the brazing alloy flowing downward through the joint. However it is recommended that the phenomenon of "force of gravity" be considered wherever possible in the design of joints for brazing.

(*A*) *Self Jigging.* The simplest and best method of keeping parts in line during brazing is to design them so the parts are self jigging.

In Fig. 9 above part *A* fits over part *B* in such a manner that it is held in line during brazing and by designing with the proper clearance the brazing alloy distributed itself throughout the joint by capillary attraction.

(*B*) *Spot Welding.* Spot welding is frequently employed to hold parts in line during the brazing cycle. This is fine where joints are to be brazed with copper filler metal and the parts have to have a snug fit. Where spot welding is used to hold parts in line for brazing with silver alloy filler metal, then a shim, the same material as the base material, may have to be inserted in the joint where it is to be spot welded to give the proper clearance. NOTE: Spot welding may be used only on those base materials for which a recommended spot welding procedure has been established (Fig. 10).

In some cases an assembly may be joined by clips spot welded to the main parts and the joint brazed to give leak tightness and fulfill other requirements. NOTE: Shims may be inserted in the joint prior to spot welding the clip in order to maintain the proper clearance. These shims are then removed before brazing (Fig. 11).

(*C*) *Tack Welding.* Tack welding is sometimes used for holding parts in line during brazing. It is especially useful for holding large heavy assemblies in line for brazing with copper filler metal. It must be remembered that unless a reducing atmosphere is used during the brazing process a small amount of oxide will remain under the tack weld and the brazing alloy will not adhere at that point. NOTE: Tack welding may be used only on those base materials for which a recommended arc welding procedure has been established.

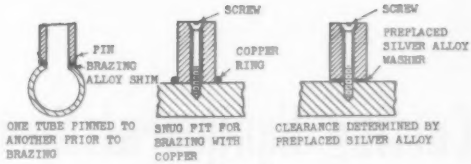

Figure 13

(*D*) *Staking, Crimping, Spinning, Expanding.* These form methods of holding parts in alignment during brazing are most useful for brazing with copper filler metal. Again it must be remembered that for brazing with alloys which require clearances other than a snug or press fit the proper clearances must be kept when the part is staked, crimped, spun or expanded.

(*E*) *Holding Parts Together with Pins, Screws or Bolts.* This is a versatile method for holding parts in alignment during brazing (Fig. 12). In most cases the pins or screws are brazed in place. It is generally a good idea to use pins or screws made of the same material as the base metal. In other words if an assembly is yellow brass use yellow brass pins or screws.

As a rule the joints can be preplaced with brazing alloy and then pinned or screwed such as is illustrated in Fig. 13:

(*F*) *Jigs and Fixtures.* Jigs and fixtures may be used both for positioning and supporting members during brazing.

In some cases it is not practical to use any of the previously mentioned methods of positioning and supporting. When that occurs it is usually necessary to devise a jig or fixture which will do the job. Care must be used in selecting the material for making the jig or fixture. Graphite has been used as a fixture but diffusion of carbon into the steel parts, for instance, must be considered. If metal fixtures or jigs are used the expansion and contraction during the brazing cycle must be considered. If the fixture is heated with the assembly to brazing temperature and it does not expand as much as the assembly then warpage or misalignment may occur.

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Cutting Equipment Speeds Steel Mill Scrap Reduction

ECONOMICAL reduction of skulls and buttons to charging-box size is an important factor in supplying home scrap for the open-hearth furnace under today's market conditions. To achieve this economy, good design of equipment for mounting the cutting blowpipe and an efficient arrangement of the cutting dock are important factors.

Figure 1 shows such a setup at one steel company's scrap yard. Skulls and buttons are powder-cut, using a cutting blowpipe. This is mounted on a machine carriage which pulls a trailer carrying a 200-lb. powder dispenser. With this unique arrangement, the powder dispenser is constantly kept in the correct position.

The arm holding the blowpipe is permanently fastened to the machine carriage, and is pivoted so that the blowpipe can be quickly positioned at any distance up to 6 or 8 ft. from the track. Weights at the opposite end of this arm counterbalance the weight of blowpipe.

A motor mechanism moves the blowpipe up and down. Limit switches prevent the carriage from running off the track.

An important feature of this design is the pantograph arrangement which permits the track, on which the carriage runs, to be moved 8 to 10 ft. out from the wall supports. The track always remains parallel to the cutting dock. Thus, the distance of the blowpipe from the dock can be adjusted so that skulls and buttons adjacent to the cutting dock can be cut to the size desired along any desired plane.

Figure 2 shows the arrangement of scrap to be cut adjacent to the concrete cutting dock. The dock has a steel face plate to prevent damage during loading. The cut is being made at a speed of about $1^1/_2$ in. per minute. Rate of cut, of course, depends on thickness of material.

Fig. 1 An Oxweld C-60 cutting blowpipe with powder-cutting attachments is mounted on a pantograph arrangement. It is possible to make cuts as much as 8 ft. from the dock

Fig. 2 Skulls and buttons can be cut one after another without delay at this steel mill scrap yard using an efficient layout

Powder-cutting is a process developed by Linde Air Products Co. An iron-rich powder, blown into an oxyacetylene flame, ignites to give the added heat needed to cut through slag-incrusted scrap, cast iron, stainless steel and difficult-to-cut nonferrous metals and alloys.

A Guide for Straight-Line Cutting

by H. P. Martin

IF YOU do a lot of straight-line cutting, here is a simple guide that will help you cut straighter and faster. And it's easy to make, too. Just follow these simple instructions:

The first thing to do is to get a 4-in. V-belt pulley. Either a steel or die-cast pulley with a $^3/_4$-in. bore will guide the attachment along a piece of angle iron. This pulley can be obtained at tool or hardware stores.

H. P. Martin is connected with the Linde Air Products Co., a division of Union Carbide and Carbon Corp., Memphis, Tenn.

***Fig. 1** The first step in making the guide is to get a V-belt pulley which will ride on a piece of angle iron. A 4-in. diameter by $^3/_4$-in. bore steel or die-cast pulley can be obtained at most tool and hardware stores*

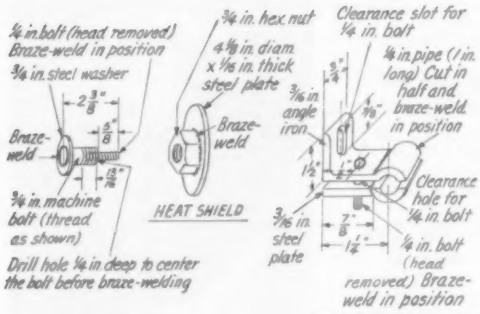

***Fig. 2** These parts are also needed. The shaft is a $^3/_4$-in. machine bolt braze welded to a steel washer. A steel disk serves as a heat shield, and the clamp is made from $^1/_4$-in. pipe braze welded to two extension pieces*

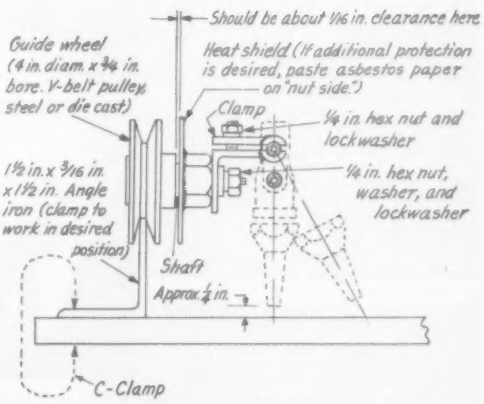
Should be about 1/16 in. clearance here
Guide wheel (4 in. diam. x ¾ in. bore. V-belt pulley, steel or die cast)
Heat shield (If additional protection is desired, paste asbestos paper on "nut side.")
Clamp
¼ in. hex nut and lockwasher
1½ in. x 3/16 in. x 1½ in. Angle iron (clamp to work in desired position)
¼ in. hex nut, washer, and lockwasher
Shaft
Approx. ¼ in.
C-Clamp

***Fig. 3** Assemble the parts as shown here. You will need two $^1/_4$-in. hex nuts and lockwashers, and a plain washer. There should be about $^1/_{16}$ in. clearance between the heat shield and the hub of the pulley*

***Fig. 4** When using the guide, keep the pulley at right angles to the work. File the top edge of the angle iron to provide a smooth, even-riding surface for the pulley*

Next make the parts shown in Fig. 2. Follow the sketches carefully. Then assemble the parts as shown in Fig. 3. If you made the parts carefully there will be about $^1/_{16}$ in. clearance between the heat shield and the hub of the pulley to provide easy rolling. Use the guide as shown in Fig. 4.

the AMERICAN WELDING SOCIETY

activities • related events

A.W.S. Expands Technical Staff

Stepped-up defense production and increased interest in new welding developments have created a greater demand for services from the SOCIETY. To better serve industry, therefore, the SOCIETY has for some time felt it should enlarge its technical staff. With this in mind, the position of Assistant to the Technical Secretary was filled by Ove Green.

Mr. Green attended public schools in Rockford, Ill., and received his B.S. in Mechanical Engineering from Illinois Institute of Technology in 1944. He entered the Navy soon after and served for fifteen months at a ship repair base in the South Pacific theater. In 1947 he joined the Research Staff of National Cylinder Gas Co., leaving to become associated with the AMERICAN WELDING SOCIETY as Assistant to the Technical Secretary.

Mr. Green has been interested in technical writing and standardization for some time and has taken graduate work at Northwestern University along these lines. His association with A.W.S. will help the SOCIETY to better serve industry.

Morrison for National Membership Chairman

I. Morrison, Past-Chairman of the A.W.S. Niagara Frontier Section, has been appointed by President H. W. Pierce to the Office of National Membership Chairman for the SOCIETY's 1951–52 Membership year.

Mr. Morrison is very well known far beyond the borders of the Niagara Frontier. At National Conventions and other important regional A.W.S. activities he will always be recognized by his cheering personality, deep interest in all A.W.S. activities and his handbag of pipes, one of which is always at work. He has been a dynamic force of vast influence in building up the membership in the Niagara Frontier Section and our national SOCIETY is fortunate indeed that, busy as he is in his capacity of Vice-President and General Manager of the Morrison Steel Products, Inc., of Buffalo, N. Y., he still finds time to devote to A.W.S. sectional, regional and national activities.

As an example of his energy he belongs to the American Society of Tool Engineers, American Society of Safety Engineers, American Society for Metals and the American Material Handling Assn., besides a number of other organizations concerned with civic and religious activity. Outside of these activities, including the Boy Scouts, he states his chief interest is his family, his wife and two daughters, of whom he is justly proud. Prior to receiving his Degree of Law at the University of Buffalo in 1928, he was educated at Buffalo Technical High School.

I. Morrison

Everyone, very soon, and in particular our Section Officers, will be hearing from Mr. Morrison. He is hopeful that all Sections are now organizing their 1951–52 Membership Committees and will advise him of their identities soon, so that he can get under way planning the organization of the coming year's National Membership Committee.

New Sustaining Members

Chrysler Corporation

Chrysler Corp., Detroit 31, Mich., manufacturer of Plymouth, Dodge, DeSoto and Chrysler passenger cars; Dodge Job-Rated trucks; Airtemp air conditioning, heating and commercial refrigeration equipment; Oilite powdered metal products; Chrysler Marine and Industrial Engines; MoPar parts and accessories; Cycleweld products and a wide variety of defense materials for the Armed Services. The Corporation's Engineering Div., consisting of more than 3000 personnel, 10 buildings and millions of dollars worth of equipment, is the outstanding activity of this sort in the automobile business and has been the source of more "firsts" in automotive engineering advancements than any other in the business. Mr. H. R. Sparks, was appointed the Sustaining Member.

Clearing Machine Corp.

Mechanical presses, straight-sided, single, double and triple action, ranging in capacities from 60 to 6000 tons.

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Automatic stock feeds to suit individual requirements.

L. J. MCDONOUGH—Sustaining (A) Member Representative

Toastmaster 1951 Banquet

The Detroit Section has announced that Vaughan Reid will act as toastmaster of the 1951 banquet of the SOCIETY to be held in Detroit on Thursday, October 18th.

Mr. Reid was born in Dundee, Scotland, on May 25, 1884. Son of David C. and Isabella Halley Reid, he graduated from the Science and Art Technical School in Dundee. He arrived in Detroit in 1905

Vaughan Reid

Lots of Different Pieces or Lots Alike...
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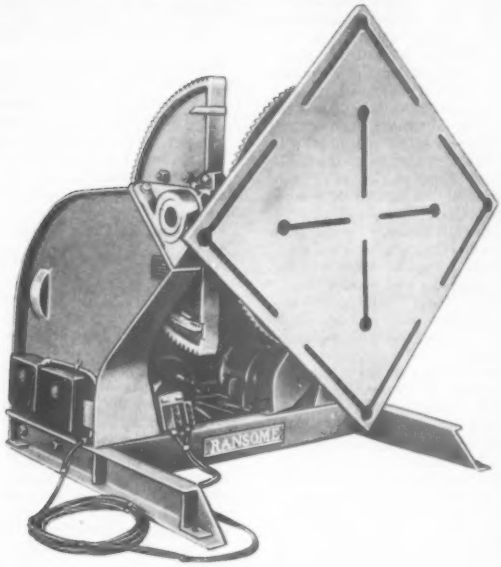

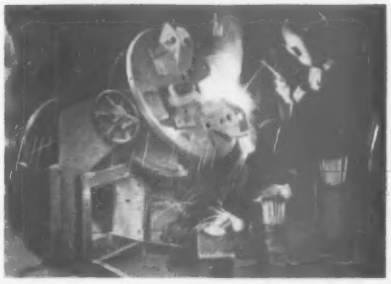

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V.1.2

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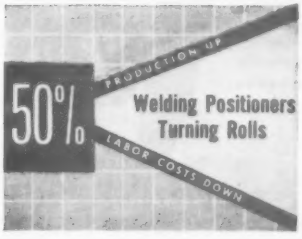


and was naturalized as a citizen in 1914. He has held many offices in the Presbyterian Church and in the Masonic Order. He is active in city and county government.

He has held many offices in technical societies and is a past chairman of the Detroit Section of the AMERICAN WELDING SOCIETY.

The City Pattern Foundry and Machine Co., of which he is President, was organized in 1913. It was the first pattern company to be honored with the Army-Navy "E" award for excellence in production.

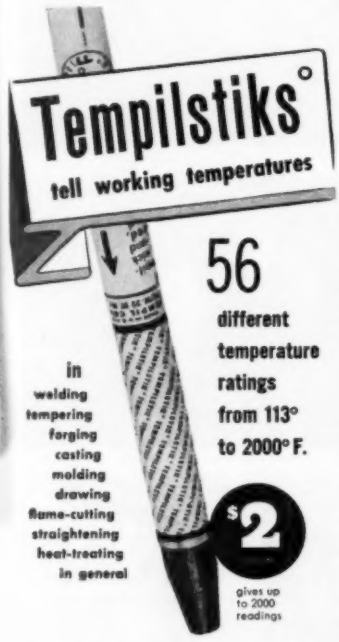
Mr. Reid has traveled extensively and is an accomplished raconteur. We are indeed fortunate in having him as our 1951 banquet toastmaster.

Detroit's 250th Birthday

Detroit is celebrating the 250th Anniversary of her founding in 1701 by Antoine de la Mothe Cadillac. During the major portion of 1951, National and International gatherings have been channeled to Detroit, including sports events, conventions, etc. The Annual Meeting of the AMERICAN WELDING SOCIETY in conjunction with the National Metal Congress and Exposition is one of these events.

Detroit's phenomenal growth and progress has been accomplished mainly through engineering and industrial achievements, making it one of the world's largest centers of massed production in the metal-working industry. The Detroit chapters of the National Engineering Societies, under the leadership and coordination of the Engineering Societies of Detroit, are playing an important role in this activity. At the Horace H. Rackham Educational Memorial in Detroit, the headquarters of the Engineering Societies of Detroit, Open House will be held during the Birthday week, July 22nd to 28th, with guided tours and an engineering exhibit accompanied by industrial motion pictures and a popular science show. The displays will be manned by personnel from the individual affiliate societies, including the Detroit Section of the AMERICAN WELDING SOCIETY. Open House will also be held by the Detroit industry for the general public. On July 28th there will be a Birthday Festival Parade, which will include an "engineering and science" float. The Institute of Radio Engineers will cooperate by providing radio and television participation in connection with engineering and science.

The Detroit Section of the AMERICAN WELDING SOCIETY is cooperating to the fullest extent. Their publicity division under the direction of E. J. Del Vecchio, has prepared an interesting article, entitled "How the Art and Science of Welding Has Improved the Scale of Living in Detroit." It deals with the history of welding and the AMERICAN WELDING SOCIETY. It points out how the level of living in the City of Detroit has improved through the art of welding since the founding of the city 250 years ago; as well as how the activities of the Detroit Section of the AMERICAN WELDING SOCIETY affect the progress of the City of Detroit and its extraordinarily active welding industries.



Tempil° corp.
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Armed Service Members

At a meeting of the Finance Committee held on Mar. 30, 1951, with subsequent approval of the Executive Committee of the A.W.S. at a meeting held on Apr. 4, 1951, both Committees were in agreement that the SOCIETY establish a moratorium on dues of those of its members entering the armed services, in the enlisted grades, as well as a special subscription rate to THE WELDING JOURNAL during the period of their service with a guarantee of reinstatement in the SOCIETY after completion of service, providing they resume normal dues payment. Accordingly, the Finance Committee acted as follows:

1. That in the case of members who have joined or been inducted into the armed forces and who, because of this are unable to meet dues payment, upon request to the SOCIETY, the name of such members shall be continued on an "inactive" membership list for the duration of the war.

2. That in the case of members who have joined or been inducted into the enlisted grades of the armed forces and who because of this are unable to meet dues payment, upon application to the SOCIETY, such members can obtain THE WELDING JOURNAL during this period at a nominal annual fee of $3.00.

3. That this information be transmitted to the Sections and suitable notice published in THE WELDING JOURNAL, and perhaps repeated for two additional times, every other month.

Meeting of Executive Committee American Welding Society

The Executive Committee held a meeting in the Engineering Societies' Bldg., New York, N. Y., on Wednesday, Apr. 4, 1951, with the following in attendance:

Members: Chairman H. W. Pierce, R. S. Donald, C. H. Jennings, H. E. Rockefeller and F. L. Plummer.

A.W.S. Staff: Assistant Secretary F. J. Mooney.

By Invitation: C. D. Evans, Chairman, TAC (in part).

TAC Recommendations

At a meeting of the Technical Activities Committee, on Apr. 3, 1951, the following items were approved by that Committee, with recommendation to the Executive Committee of the SOCIETY for final approval thereon:

(a) *Committee on Standard Mechanical Tests for Welds.* The Technical Activities Committee voted to recommend to the Executive Committee that the A.W.S. Committee on Standard Mechanical Tests for Welds be disbanded.

Action: The Executive Committee so approved.

(b) *Tentative Standard Specifications for Field Welding of Steel Water Pipe Joints.* The Technical Activities Committee voted to recommend to the Executive Committee that the Tentative Standard Specifications for Field Welding of Steel Water Pipe Joints be advanced to the status of a "Full Standard" of the AMERICAN WELDING SOCIETY.

Action: The Executive Committee so approved.

(c) *Milwaukee School of Engineering.* The Technical Activities Committee voted to recommend to the Executive Committee that the A.W.S. Resistance Welding Committee organize a special subcommittee comprising J. B. Welch, Chairman, J. J. Chyle, C. D. Evans, S. A. Greenberg and Julius Heuschkel, to serve in an advisory capacity to the Milwaukee School of Engineering in organizing a training program for supervisory personnel for resistance welding operations.

Action: The Executive Committee voted: (1) that the Technical Activities Committee advise the Educational Committee of the complete problem; (2) that the Educational Committee then prepare a program to assist in the preparation of information and be a cooperating committee with the TAC Subcommittee "Committee on Minimum Requirements of Instructions for Welding Operators"; (3) the Educational Committee render report to the Board of Directors as to its recommendations for handling requests of this nature; (4) that necessary technical data be secured from the Technical Activities Committee; and (5) if deemed advisable, the Technical Activities Committee prepare a standard on the training of resistance welding personnel.

INDEX TO ADVERTISERS

Air Reduction Sales Co. ..... Outside back cover
Alloy Rods Co. 663
The American Brass Company 677
American Chain and Cable Co. 647
American Manganese Steel Division 655
Ampco Metal, Inc. 653
Bastian-Blessing Co. 662
Becker Brothers Carbon Co. 658
The Champion Rivet Company 644
Dockson Corporation 660
Eutectic Welding Alloys Corporation 646
Hobart Brothers Company 583
The International Nickel Company, Inc. 645
Jackson Products ..... Inside back cover
The Lincoln Electric Company 649
Linde Air Products Company, Division of Union Carbide and Carbon Corporation 586
P. R. Mallory & Co., Inc. 585
Metal & Thermit Corporation 584
Mid-States Welder Mfg. Co. 664
National Carbide Company 656
National Cylinder Gas Company 666, 667
Page Steel and Wire Division 647
Pennsylvania Optical Company 657
Square D Company 661
Tempil° Corporation 642
Tweco Products Company ..... Inside front cover
Union Carbide and Carbon Corp., Linde Air Products Company 586
Victor Equipment Company 588
Westinghouse Electric Corporation 658
J. H. Williams & Co. 660
Worthington Pump and Machinery Corporation 641

WELDING
CODES STANDARDS and SPECIFICATIONS

Are you fully informed on the latest welding standards available? Have you missed any of the earlier standards? This column is published as a regular monthly feature of The Welding Journal to keep you abreast of A.W.S. technical standards, which are universally recognized as the most authoritative source of welding information.

The list of publications shown below is only partial; it is changed from month to month.

Keep informed—Read this column regularly

A. FUNDAMENTALS OF WELDING

Definitions, Symbols, Testing, Filler Metal

A2.0-47 Standard Welding Symbols	**$1.00**
A2.1-47 Symbols Wall Chart	**50c**
A3.0-49 Standard Welding Terms and Their Definitions	**$1.00**
A3.1-49 Master Chart of Welding Processes and Process Charts	**50c**
A3.0-49 and A3.1-49 together	**$1.50**
A4.0-42 Standard Methods for Mechanical Testing of Welds (with 1945 Supplement)	**50c**
***A5.1-48T Specifications for Mild Steel Arc-Welding Electrodes (Tentative)**	**35c**
***A5.2-46T Specifications for Iron and Steel Gas-Welding Rods (Tentative)**	**25c**
***A5.4-48T Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Electrodes (Tentative)**	**25c**
***A5.5-48T Specifications for Low-Alloy Steel Arc Welding Electrodes (Tentative)**	**35c**
***A5.6-48T Specifications for Copper and Copper-Alloy Metal Arc Welding Electrodes (Tentative)**	**25c**
A6.0-40 Recommended Procedure to be Followed in Preparing for Welding or Cutting Certain Types of Containers Which Have Held Combustibles	**50c**

NOTE: 25% discount to A and B members and 15% discount to C members of AWS on copies of any codes and standards listed above except starred items.

Send your orders, or requests for Order Forms containing complete list of AWS publications to:

Dept. T,
American Welding Society
33 West 39th Street
New York 18, N. Y.

(d) *Appointment of Assistant to the Technical Secretary.* Upon motion, the Executive Committee approved the employment of Mr. Green with the Society as Assistant to the Technical Secretary.

Acceptance Finance Committee Minutes

The Chairman called for review of the minutes of the Finance Committee meeting, held on Mar. 30, 1951, and the Auditor's Report for the six months' period ended Feb. 28, 1951.

Action: Upon motion, said minutes and Auditor's Report were accepted and actions taken by the Finance Committee, at meeting of Mar. 30, 1951, met with the unanimous approval of the Executive Committee.

Annual Meeting

With reference to Item 9 "Annual Meeting" of minutes of Feb. 12, 1951, Board of Directors' meeting, the Board of Directors, at that meeting, acted as follows: "After a brief discussion, it was decided that this item should receive the specific attention of the Executive Committee at its next meeting, that Committee to determine the scope, purpose and requirements of the A.W.S. Annual Meeting, or to decide whether or not the special committee for the purpose should be appointed." At this meeting, President Pierce stated that this item should be given serious consideration and, accordingly, requested authorization to appoint a committee consisting of three to determine the scope, purpose and requirements of the A.W.S. Annual Meeting.

Action:

The Executive Committee so authorized.

Appointment Advertising Manager

At meeting of The Welding Journal Committee, on Feb. 9, 1951, that Committee made recommendation to the Board of Directors that W. Spraragen, Editor of The Welding Journal, assume responsibility for advertising solicitation at once.

Action: The Executive Committee, acting in behalf of the Board of Directors, so approved

Appointment Manufacturers Committee

President H. W. Pierce requested the appointment of G. C. Mutch, Revere Copper and Brass, Inc., Rome, N. Y., to serve on the A.W.S. Manufacturers Committee, with term expiring at the close of the 1950–51 administrative year.

Action: The Executive Committee so approved.

Appointment Reserve Funds Committee

President H. W. Pierce requested the appointment of R. D. Thomas, Sr., Arcos Corp., Philadelphia, Pa., to serve on the A.W.S. Reserve Funds Committee, with term expiring October 1955.

Action: The Executive Committee so approved.

Appointment Memorial Resolutions Committee

On Feb. 26, 1951, P. M. Mattern of Wilson Welder and Metals Co., New York City, suddenly passed away. Mr. Mattern was very active in Society affairs. He was a member of the Society since 1936 and for seven consecutive years, 1944–51, was Secretary-Treasurer of the New Jersey Section. President Pierce requested authorization to appoint a committee of two to draw up suitable Memorial Resolutions for transmittal to Mr. Mattern's family and company.

Action: The Executive Committee so authorized.

A.W.S. Student Chapter

Le Tourneau Technical Institute, located at Longview, Tex., having met all the qualifications necessary for the establishment of a Student Chapter requested that formal authority to operate as the Le Tourneau Technical Institute Student Chapter of the American Welding Society be granted.

Action: The Executive Committee so approved.

The Welding Equipment Section of N.P.A. Is Enlarged

Dale D. Spoor, Chief of the Welding Equipment Section, General Industrial

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BY USING CHAMPION BLUEDAC ELECTRODES, GUESSWORK IS ELIMINATED IN ROLLING MILL REPAIR WORK. IT IS ESPECIALLY DESIGNED TO GET THE JOB DONE FASTER... MAINTAIN HIGHER PRODUCTIVITY WITH LITTLE OR NO DOWNTIME.
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Oxy-Acetylene	"43" Monel Gas Welding Wire	For welding heavy sections of Monel for acid pickling service — no flux required.
Metal-Arc	"130X" Monel Welding Electrode D.C.	For welding Monel
Metal-Arc	"140" Monel Welding Electrode D.C.	For welding Monel to steel and overlaying Monel on steel
Submerged Melt	"50" Monel Wire	For welding Monel
Inert Gas Metal-Arc	"60" Monel Wire	For welding Monel

NICKEL

Oxy-Acetylene	"41" Nickel Gas Welding Wire	For welding of pure Nickel—no flux required
Metal-Arc	"131" Nickel Welding Electrode D.C.	For welding pure Nickel or "L" Nickel
	"141" Nickel Welding Electrode D.C.	For welding Nickel to steel; overlaying Nickel on steel
Submerged Melt	"51" Nickel Wire	For welding pure Nickel
Inert Gas Metal-Arc	"61" Nickel Wire	For welding pure Nickel

INCONEL

Oxy-Acetylene	"42" Inconel Gas Welding Wire	For welding Inconel* using INCO "2" Gas Welding Flux
Metal-Arc	"132" Inconel Welding Electrode A.C.-D.C.	For welding Inconel; and Inconel to steel
Metal-Arc	"133" 80/20 Nickel-Chromium Welding Electrode A.C.-D.C.	For welding Inconel to steel
Submerged Melt	"52" Inconel Wire	For welding Inconel
Inert Gas Metal-Arc	"62" Inconel Wire	For welding Inconel

70/30 COPPER-NICKEL

Oxy-Acetylene	"47" 70/30 Copper-Nickel Gas Welding Wire	For welding 70/30 Copper-Nickel using INCO "1" Gas Welding and Brazing Flux
Metal-Arc	"137" 70/30 Copper-Nickel Welding Electrode D.C.	For welding 70/30 Copper-Nickel
Submerged Melt	"57" 70/30 Copper-Nickel Wire	For welding 70/30 Copper-Nickel

"K" MONEL

Oxy-Acetylene	"44" "K" Monel Gas Welding Wire	For welding "K"* Monel, using 2 parts INCO "2" Gas Welding Flux and 1 part Lithium Fluoride
Metal-Arc	"134" "K" Monel Welding Electrode D.C.	For welding "K" Monel
Inert Gas Metal-Arc	"64" "K" Monel Wire	For welding "K" Monel

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NICKEL-CLAD STEEL

Metal-Arc	"141" Nickel Welding Electrode D.C.	For welding Nickel side only

"L" NICKEL-CLAD STEEL

Metal-Arc	"141" Nickel Welding Electrode D.C.	For welding "L"* Nickel side only

MONEL-CLAD STEEL

Metal-Arc	"140" Monel Welding Electrode D.C.	For welding Monel side only

INCONEL-CLAD STEEL

Metal-Arc	"133" 80/20 Nickel-Chromium Welding Electrode A.C.-D.C.	For welding Inconel side only

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INCO "1" Gas Welding and Brazing Flux—For the welding and brazing of copper-nickel and other copper alloys.

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INCO "3" Gas Welding Flux — For the welding of Monel and other Nickel-copper alloys.

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Metal-Arc	NI-ROD* Electrode A.C.-D.C.	For machinable welds in cast iron
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Definition of Terms • Technology Temperatures of application • Joining Methods: Torch Joining; Arc Joining; Induction Joining; Furnace Joining; Inert Arc Joining • Recommendations of Types of Joint and Heating Methods • Design Information: Square Butt Joint; Lap Joint; Flange Joint; Beveled Butt Joint; Fillet Weld; Overlay • Fluxing and Removal of Flux • Inspection and Control • Heat-treating of Welded Parts, and Welding of Heat-treated Parts.

—AND SCORES MORE . . . INCLUDING sketches and data on welding alloys for use with: cast iron, all steels, stainless steel, copper, brass, bronze, nickel and its alloys, magnesium, aluminum, hard and machinable overlays, etc., etc., etc.!

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Equipment Division, N.P.A., announced the appointment of two men to assist in handling the problems of the Welding Industry.

Preston M. (Pete) Hall of Warren, Ohio, has joined the section to head up all of the matters concerning Resistance Welding Machines, Controls and Electrodes. Pete Hall is well known in the Resistance Welding Field having had his own business in the design and manufacture of spot welders in Worcester, Mass., and in Warren, Ohio, for a good many years. In 1946 and 1947 Mr. Hall was with the Resistance Welders Manufacturers Assn. writing technical articles on resistance welding and reporting new developments in the industry. The industry will recall that Pete Hall was in Washington during World War II on the War Production Board and handling the resistance welding problems at that time, and will welcome the fact that an experienced man is now on the job for these products.

Another familiar face to the Welding Industry is Harold R. (Smitty) Smith who was in the Welding Equipment Section of the War Production Board from 1942 to 1945. Smitty is again back on the job handling all of the C.M.P. Applications and otherwise assisting in maintaining production in the Welding Industry. After the war Smitty stayed on in Washington for a year and a half handling surplus materials for the War Assets Administration.

With this increased organization of experienced men it is hoped that the Welding Industry will be adequately represented so that its problems will receive the attention this important industry deserves.

N.P.A. Committee

The National Production Authority, U. S. Department of Commerce, announced the membership list of the Welded & Seamless Steel Tubing Industry Advisory Committee as follows:

W. J. Thomas, Sales Manager, Babcock & Wilcox Tube Co., Beaver Falls, Pa.

F. W. Sexauer, Sales Manager, Brainard Steel Corp., Warren, Ohio.

Walter Wiewell, Vice-President in Charge of Sales, Crucible Steel Corp., Oliver Bldg., Pittsburgh, Pa.

Lee Mullen, Vice-President, Sales, Globe Steel Tube Co., Milwaukee, Wis.

Aaron Waines, Sales Manager, Ohio Seamless Tube Co., Shelby, Ohio.

B. R. Mueller, Assistant Sales Manager, Tubular Specialties, Pittsburgh Steel Co., Pittsburgh, Pa.

J. A. Ireland, Manager of Sales, Steel & Tubes Division, Republic Steel Corp., Cleveland, Ohio.

S. L. Willis, President, Standard Tube Co., 24400 Plymouth Road, Detroit 28, Mich.

R. H. Gabel, Vice-President of Operations, Superior Tube Co., Norristown, Pa.

W. E. Taggart, Manager of Tubular Sales, Timken Roller Bearing Co., Steel & Tubes Division, Canton, Ohio.

H. L. Bialock, Manager of Sales, Tubular Specialties, National Tube Co., Gary, Ind.

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TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

32nd Annual Meeting
week of October 15, 1951

HOTEL BOOK CADILLAC, DETROIT, MICH.

Welding and cutting demonstration will be featured at the National Metal Exposition held during the week at the Michigan State Fairgrounds

TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the sessions. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

MONDAY MORNING, OCTOBER 15th

Two Simultaneous Sessions

STRUCTURAL WELDING

Chairman—La MOTTE GROVER
Air Reduction Sales Co.

Co-Chairman—MARTIN P. KORN
Consulting Engineer

Yield Strength of Welded Continuous Beams
by C. H. YANG and L. S. BEEDLE, Lehigh University, Fritz Engineering Lab., and H. G. JOHNSTON, University of Michigan

Column Strength Under Combined Bending and Thrust
by R. L. KETTER and L. S. BEEDLE, Lehigh University, Fritz Engineering Lab., and B. G. JOHNSTON, University of Michigan

Estimating Weldments and Welded Structural Steel
by CHAS. F. FRANTZ, Lehigh Structural Steel Co.

Surface Conditioning of Structural Steel by Welding
by R. E. SOMERS and H. C. VON BLOHN, Bethlehem Steel Co.

RESISTANCE WELDING

Chairman—JACK OGDEN
Fisher Body Div., General Motors Co.

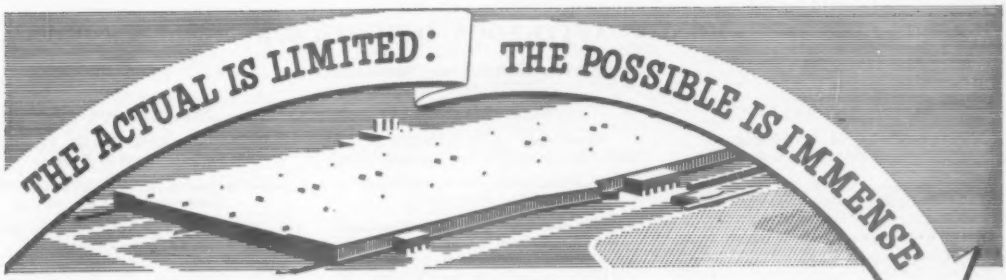
Co-Chairman—B. L. WISE
National Electric Welding Machine Co.

Physical and Metallurgical Characteristics of Spot Welding Titanium
by M. L. BEGEMAN, J. C. FONTANA and FRANK W. MCBEE, JR., The University of Texas

The Application of Spot and Seam-Welding to Design
by S. P. JENKINS and THOMAS E. PIPER, Northrop Aircraft, Inc.

Spot and Projection Welding Using Magnetic Electrode Force
by WILLIAM E. KLINGEMAN and H. H. KRUER, Precision Welder and Machine Co.

A Case of Power
by MYRON ZUCKER, Myron Zucker Engineering Co., JERRY GERALDS, Midwest Wire Products Co., and PAUL DUKER, The Detroit Edison Co.



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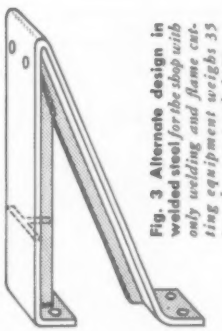

Fig. 3 Alternate design in welded steel *for the shop with only welding and flame cutting equipment weighs 35 pounds . . . costs only $4.70 . . . a saving of 48% over Figure 1.*

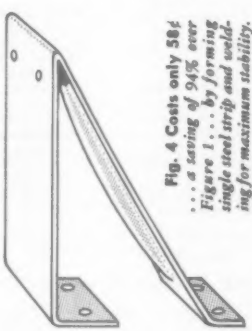

Fig. 4 Costs only 58¢ . . . a saving of 94% over Figure 1 . . . by forming single steel strip and welding for maximum stability. Weighs only 9 pounds.

the ACTUAL

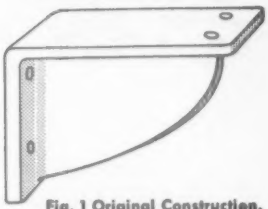

Fig. 1 Original Construction. *Machinery bracket weighs 39 pounds. Has ⅜" and ½" sections. Requires milling and drilling. Costs $9.10.*

increasing the YIELD

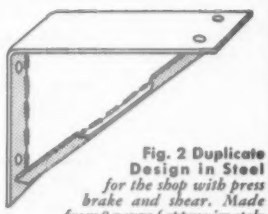

Fig. 2 Duplicate Design in Steel *for the shop with press brake and shear. Made from 8 gauge (approximately ⅛") sheet . . . saves 27 pounds of metal.* Costs $5.13 less than original construction.

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THE LINCOLN ELECTRIC COMPANY

CLEVELAND 1, OHIO

MONDAY AFTERNOON, OCTOBER 15th

Three Simultaneous Sessions

RESISTANCE WELDING

Chairman—J. RANDALL
Ford Motor Car Co.

Co-Chairman—R. C. McMASTER
Battelle Memorial Institute

Seam Welding Containers Automatically
by C. S. SELTZER, Swift Electric Welder Co.

Spot and Seam Welding of Nimonic and Similar Heat-Resistant Alloys
by J. SOLOMON, Sciaky Bros., Inc.

Temperature Distribution During the Flash Welding of Steel
by ERNEST F. NIPPES, W. F. SAVAGE and J. J. McCARTHY, Rensselaer Polytechnic Institute

WELDABILITY

Chairman—A. B. KINZEL
Union Carbide and Carbon Research Labs.

Co-Chairman—R. S. ARCHER
Climax Molybdenum Co.

Microcracks and the Low-Temperature Cooling Rate Embrittlement of Arc Welds in Mild Steel
by PROF. A. E. FLANIGAN, Dept. of Engineering, University of California

Effect of Sub-Critical Cooling Rate on Strain and Quench Aging of Structural Steels
by C. FELMLEY, C. HARTBOWER and W. S. PELLINI, Metallurgy Div., Naval Research Lab.

NONFERROUS

Chairman—G. O. HOGLUND
Aluminum Company of America

Co-Chairman—I. C. MATTSON
Dow Chemical Co.

Tensile Tests and Metallurgical Studies of Welded Copper Joints
by R. J. MOSBORG, R. W. BOHL, F. L. HOWLAND and W. H. MUNSE, Dept. of Civil Engineering, University of Illinois

Welding Iron-Bearing Alpha Aluminum Bronze
by F. EMERY GARRIOTT, Weldrod Dept., Ampco Metal, Inc.

Pressure Welding Aluminum at Various Temperatures
by M. A. MILLER and G. W. OYLER, Aluminum Research Labs.

MONDAY EVENING, OCTOBER 15th

President's Reception

TUESDAY MORNING, OCTOBER 16th

Two Simultaneous Sessions

SHIP STRUCTURE

Chairman—CAPT. E. A. WRIGHT
U.S.N., Bureau of Ships

Co-Chairman—COMMANDER D. B. HENDERSON
U. S. Coast Guard

Work of the Ship Structure Committee
by REAR ADMIRAL K. K. COWART, U. S. Coast Guard

Low-Carbon Steel: Subcritical Heating vs. Transition Temperatures
by L. J. KLINGER, E. B. EVANESKES and WM. M. BALDWIN, Case Institute of Technology

Studies of Tests for Evaluating Welded Ship Steels
by C. B. VOLDRICH and P. J. RIEPPEL, Battelle Memorial Institute

Stress Studies of Bulkhead Intersections for Welded Tankers
by W. R. CAMPBELL and L. K. IRWIN, National Bureau of Standards

The Influence of Composition and Steel-Making Practice upon Ship-Plate Quality
by H. M. BANTA, Battelle Memorial Institute

FUNDAMENTAL STUDIES OF ARC WELDING

Chairman—W. B. KOUWENHOVEN
Johns Hopkins University

Co-Chairman—R. W. CLARK
General Electric Co.

The Effect of Power Supply Characteristics on D.-C. Welding
by JACK B. KEYTE, Dept. of Welding Engineering, Ohio State University

Welding Characteristics of Submerged Arc with Three-Phase Power
by E. A. CLAPP, Union Carbide and Carbon Research Labs., Inc., and NORMAN G. SCHREINER, Linde Air Products Co.

Tools for Predetermining Preheat and Interpass Temperatures for Submerged Arc Welds
by CLARENCE E. JACKSON and ARTHUR F. SHRUBSALL, Union Carbide and Carbon Research Labs., Inc.

TUESDAY MORNING, OCTOBER 16th

Inspection Trip

Arrangements have been made for an Inspection Trip to the plants of the Ford Motor Co.

TUESDAY AFTERNOON, OCTOBER 16th

Three Simultaneous Sessions

SHIP STRUCTURE

Chairman—DAVID P. BROWN
American Bureau of Shipping

Co-Chairman—FINN JONASSEN
National Research Council

Welded Reinforcement of Openings in Structural Steel Plates
by D. VASARHELYI and R. A. HECHTMAN, University of Washington

Evaluation of Welding Procedure by Direct Explosion Testing
by G. S. MIKHALAPOV, Metallurgical Research and Development Co.

Investigation of Factors Which Determine Welded Performance
by C. HARTBOWER and W. S. PELLINI, Naval Research Lab.

Upper and Lower Transition in Charpy Tests
by W.J. HARRIS, JR., J. A. RINEBOLT and R. BARING, Naval Research Lab.

HARD FACING AND FLAME HARDENING

Chairman—E. V. DAVID
Air Reduction Sales Co.

Co-Chairman—L. W. BOELTER, Climax Manufacturing Co.

Control of Rail-End Hardening
by La MOTTE GROVER, Air Reduction Sales Co.

Hard Facing for Impact
by HOWARD S. AVERY, American Brake Shoe Co.

Development of Fused Metallized Coatings
by HARRISON S. SAYRE, U. S. Naval Engineering Experiment Station

RESISTANCE WELDING

Chairman—F. R. HENSEL
P. R. Mallory & Co.

Co-Chairman—T. EMBURY JONES
Precision Welder & Machine Co.

Trends in Electronic Nonsynchronous Resistance Welding Controls
by STUART C. ROCKAFELLOW, Robatron Corp.

Flash Welding of Components for Aircraft and Similar Applications
by J. H. COOPER, The Taylor-Winfield Corp.

Fatigue Strength of Spot-Welded Light Alloy Joints
by H. KIHARA, President, The Japan Welding Society

TUESDAY EVENING, OCTOBER 16th

ADAMS LECTURE

WEDNESDAY MORNING, OCTOBER 17th

Three Simultaneous Sessions

PRODUCTION WELDING

Chairman—A. E. LINDSEY
Ford Motor Co.

Co-Chairman—L. P. DEMPSEY
American Metal Products Company

Welding Heat Exchanger for the Chemical Industry
by JOHN W. MORTIMER, Professional Engineer

Product Design for Welding
by JOHN MIKULAK, Worthington Pump and Machinery Corp.

Welding Fixtures for Use with Submerged Arc
by J. P. BERKELEY, Berkeley Equipment Co.

PRESSURE VESSELS

Chairman—H. C. BOARDMAN
Chicago Bridge & Iron Co.

Co-Chairman—L. C. BIBBER
Carnegie-Illinois Steel

Unfired Pressure Vessel for the Petroleum Industry
by WALTER SAMANS, Consulting Engineer

Effect of Fabrication Processes on Steel Used in Pressure Vessels
by DR. S. S. TÖR, J. M. RUZEK, DR. R. STOUT, Lehigh University, Fritz Engineering Lab.

Biaxial Fatigue Tests on Flat Plate Specimens
by R. U. BLASER, L. F. KOOISTRA and J. T. TUCKER, JR., The Babcock & Wilcox Co.

Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports
by LEONARD P. ZICK, Chicago Bridge and Iron Co.

GAS CUTTING

Chairman—G. V. SLOTTMAN
Air Reduction Sales Co.

Co-Chairman—H. E. ROCKEFELLER
Linde Air Products Co.

Oxygen Cutting of Defense Equipment Materials
by A. H. YOCH, Air Reduction Sales Co.

Heavy Scrap Cutting
by L. P. ELLY, Bethlehem Steel Co.

Powder-Washing for Metal Removal
by R. S. BABCOCK, Linde Air Products Co.

WEDNESDAY AFTERNOON, OCTOBER 17th

Three Simultaneous Sessions

WELDABILITY

Chairman—J. LYELL WILSON
Consulting Naval Architect

Co-Chairman—J. W. HALLEY
Inland Steel Co.

The Relation of Notch Strains to Bend Angles in the Notched-Bend Test
by PROF. A. E. FLANIGAN, University of California, and ERNEST M. EMERY, North American Aviation Co.

Repeated Load Tests on Welded and Prestrained Steel
by DR. S. S. TÖR, J. M. RUZEK, DR. R. D. STOUT, Lehigh University, Fritz Engineering Laboratory

The Micro-Mechanism of Fracture in the Tension-Impact Test
by W. H. BRUCKNER, University of Illinois

WELDING AND BRAZING

Chairman—A. N. KUGLER
Air Reduction Sales Co.

Co-Chairman—R. E. POWELL
Western Electric Co.

Nested Electrodes for Metal Arc Welding
by W. A. SNYDER, University of Washington

Welding in Steel Mill Maintenance During Defense Period
by R. L. DEILY, Air Reduction Sales Co.

Dilution and Diffusion Aspects of Brazing
by R. D. WASSERMAN and JOSEPH F. QUAAS, Eutectic Welding Alloys Corp.

STAINLESS STEELS

Chairman—G. E. CLAUSSEN
Reid-Avery Co.

Co-Chairman—W. O. BINDER
Union Carbide and Carbon Research Labs.

Welding of High-Alloy Steel Castings
by R. D. THOMAS, JR., Chairman of WRC Committee on the subject

The Structural Stability of Welded Joints Between Dissimilar Metals in High-Temperature Service
by R. W. EMERSON, Pittsburgh Piping & Equipment Co.

WEDNESDAY EVENING, OCTOBER 17th

UNIVERSITY RESEARCH CONFERENCE

THURSDAY MORNING, OCTOBER 18th

Three Simultaneous Sessions

EDUCATIONAL

Chairman—R. S. GREEN
Ohio State University

Co-Chairman—J. HEUSCHKEL
Westinghouse Electric Corp.

Selecting and Training Welding Operators for the Defense Program
by A. N. KUGLER, Air Reduction Sales Co.

Metallurgy for the Welding Student
by J. D. PATERSON, Cass Technical High School

Tentative Standards for School Welding Shops
by CARL H. TURNQUIST, Cass Technical High School

Welding Instruction in the Public Schools
by A. D. ALTHOUSE, Detroit Public Schools

WELDABILITY

Chairman—W. F. HESS
Rensselaer Polytechnic Institute

Co-Chairman—D. H. COREY
Detroit Edison Co.

The Arc Welding of Carbon-Molybdenum Steel Pipes
by F. J. WINSOR, E. I. du PONT de NEMOURS and Co.

Residual Stresses Due to Circumferential Welds in Seamless Mild Steel Pipe
by L. J. PRIVOZNIK, Standard Oil Co. (Ind.)

Heat Treating Properties of Low-Hydrogen Electrode Weld Metal
by D. C. SMITH and W. G. RINEHART, Harnischfeger Corp.

High-Temperature Welded Joints
by R. H. ENGLISH, National Alloy Steel Co.

INERT-ARC WELDING

Chairman—A. J. ERLACHER
United Engineers & Constructors, Inc.

Co-Chairman—K. L. WALKER
Foster Wheeler Corp.

Inert Gas Shielded Metal Arc Welding of Magnesium
by PAUL KLAIN, Dow Chemical Co.

Aircomatic Welding of Ferrous Metals
by E. Di LIBERTI, Air Reduction Co.

Metal Transfer in Shielded Inert Gas Metal Arc Welding
by R. T. BREYMEIER, Union Carbide and Carbon Research Lab.

High-Speed Consumable Electrode Machine Welding for Aircraft
by BERNARD GROSS and R. A. SMITH
Rohr Aircraft Corporation

THURSDAY AFTERNOON, OCTOBER 18th

Symposium

Filler Metal Specifications for Inert-Gas and Submerged-Arc Welding

BUSINESS MEETING
BOARD OF DIRECTORS MEETING

THURSDAY EVENING, OCTOBER 18th

ANNUAL DINNER
Presentation of Awards

FRIDAY MORNING, OCTOBER 17th

Two Simultaneous Sessions

INERT-ARC WELDING

Chairman—O. H. KUHLSE
General American Transportation Co.

Co-Chairman—H. N. SIMMS
Black, Sivalls & Bryson, Inc.

Aircomatic Welding-Refinery Components and Pressure Vessels
by S. YACZKO, United Engineers & Constructors, Inc.

Shielded Inert Gas Metal Arc Welding
by H. T. HERBST, Linde Air Products Co.

Performance of High-Strength Aluminum Alloy Weldments
by W. R. APBLETT and W. S. PELLINI, Metallurgy Div., Naval Research Lab.

Thoriated Tungsten Electrodes—Their Welding, Characteristics and Applications
by G. J. GIBSON and R. O. SEITZ, Air Reduction Sales Co.

METALLIZING

Chairman—W. B. MEYER
Nooter Corp.

Co-Chairman—S. A. GREENBERG
Secretary A.W.S. Committee on Metallizing

Fundamentals of the Metallizing Process
by F. J. KELLER, Aluminum Research Labs.

New Developments on Metallizing During the Past Ten Years
by SAM TOUR, Sam Tour and Co.

Typical Applications of Metallizing
by K. B. SMITH, Dix Engineering Co.

PERSONNEL

John Fox Joins A. O. Smith

John Fox, a member of the SOCIETY and formerly district manager for Machinery and Welder Corp., has been named representative of the A. O. Smith Welding Products Div. in the Greater St. Louis area according to an announcement by L. F. Vonier, A. O. Smith welding sales manager.

J. S. Roscoe Appointed Director of Purchasing for Lincoln Electric

The appointment of J. S. Roscoe as Director of Purchasing has been announced by The Lincoln Electric Co., Cleveland, Ohio. Roscoe has been with Lincoln since 1924 when he was graduated from Ohio State University with a degree in Electrical Engineering.

He has been continuously active since then as a welding engineer and District Manager, responsible for welding development in Syracuse, Pittsburgh and Chicago. As District Manager in Syracuse from 1925 to 1944 he pioneered in the application of automatic welding. One of his early developments was the automatic carbon-arc welding of copper cooling fins to engine cylinders. He also established the procedures for welding the first all-welded freighter on the Great Lakes.

J. S. Roscoe

As District Manager in Pittsburgh from 1944 to 1947 he played an important part in the early development of automatic welding on steel mill equipment. Procedures established for surfacing rolls and other mill parts have since become a vital part of mill maintenance programs. He has been District Manager in the Chicago area since 1947, from where he moved to Cleveland to assume responsibility for Purchasing.

He has been an active member of the AMERICAN WELDING SOCIETY, organizing the Syracuse Chapter and serving as an officer and Director of Chapters in Pittsburgh and Chicago. He has had published numerous technical articles on the development of welding. He is a member of the Western Society of Engineers and the Electrical Engineering Honorary Society, Eta Kappa Nu. He is married and has two children.

Flohr Elected Rotary Director

Carlos Flohr, partner of the Flohr & Co. Metal Fabricators of Seattle, Wash., has been elected to the board of directors of the Rotary Club of that city.

Seattle's Rotary Club was the fourth to be organized anywhere in the world and is one of the largest of its kind, with a membership of 485.

Flohr is a member of the AMERICAN WELDING SOCIETY, and is a board member of the Sheet Metal Contractors Assn., the Washington Metal Trades and the Washington Employers, Inc.

Wetterstrom Joins Graver

Dr. Edwin Wetterstrom has joined the Research and Development staff of Graver Tank & Mfg. Co., Inc., an analytical engineer. His duties are to pursue new and independent lines of research in problems of the storage of volatile liquids. These avenues are a continuation of his advanced work at Purdue University, where he held the Graver Research Fellowship and conducted theoretical and experimental investigations related to practical problems in new Graver projects. He has had extensive experience in the design of pressure vessels and steel structures, and has been the author of several important articles on engineering design, which have been published in professional journals.

For the Pressure Vessel Research Committee of the Welding Research Council, he was project engineer in change of analysis. Besides being a registered engineer, he holds his Ph.D. and Master's degree in Engineering Mechanics from Purdue and his Bachelor's degree in Mechanical Engineering from Illinois Institute of Technology.

A native of Chicago, Dr. Wetterstrom was for several years on the development staff of the Continental Can Co. He then became an instructor of graduate engineering courses at Purdue's School of Civil Engineering and Engineering Mechanics.

$1718 Saved

. . . by "Bronze-Facing" large gear with wear-resistant Ampco-Trode* 300

HERE'S a large 10'6" diameter tube-mill gear with 120 teeth and an 11-inch face. A new one costs $2,148. This one was made better than new by "Bronze-Facing" it with wear-resistant Ampco-Trode 300 for only $530. Time required for the entire job — 82 hours.

You, too, can enjoy the savings in time and money made possible by "Bronze-Facing" with Ampco-Trode. Other advantages are: longer life and less down time. For instance, after 5 months' service in a cement mill, this gear showed little or no wear — thanks to the 300 Brinell tooth-surface hardness provided by Ampco-Trode 300.

In these days of shortages and long deliveries you'll find Ampco-Trode bronze electrodes a big help. Get a supply today from your Ampco distributor or write us.

W-113

AMPCO

Ampco Metal, Inc.
Milwaukee 46, Wisconsin

It's Production-Wise to Ampco-ize

*Reg. U. S. Pat. Off., Ampco Metal, Inc.

NEWS OF THE INDUSTRY

Stainless Steel Display

A traveling display panel, prepared by the Committee of Stainless Steel Producers, American Iron and Steel Institute, and featuring the advantages of stainless steel as a building material, is now being exhibited in 14 schools of architecture in the East and Midwest.

The stainless steel exhibit is one of a number on construction materials furnished by manufacturers and their associations in cooperation with the Techniques and Materials organization, a group formed to circulate technical information to colleges and universities. The displays are designed to familiarize architectural students with outstanding types of modern building materials.

By means of photographs and actual samples of the metal, the stainless steel display emphasizes the usefulness and enduring beauty of stainless for architecture. One section of the panel demonstrates the weldability of stainless, and the technique of blending the weld to the adjacent metal.

Efficient Use of Cylinders

We quote herewith from a letter sent by Sec. F. R. Fetherston of the Compressed Gas Assn. to members of this organization:

"Last November, the Association through its Bulletin service, called attention to the increasing demand for new cylinder production and factors which make the procurement of new cylinders a problem. The uncertainty of the military impact upon the cylinder market, as well as problems involving the availability of steel, and certain of the steel alloying elements, impress us with the real necessity for more efficient utilization of existing cylinder supplies.

"Without the conscientious and earnest assistance of your customers, however, little can be done to maintain a proper degree of efficiency in the use of these containers. During World War II cylinder turn-over was accelerated to an amazing extent simply through customer cooperation. The result of course made it possible to meet the unusual demand for gases and everyone knows that emergencies such as we face today create ever-increasing need for these products.

"It is therefore suggested that your company pass along to its customers a request for cooperation with the compressed gas industry by returning empty cylinders as rapidly as possible. You are best able to make specific recommendations to your customers, but we strongly urge that this view of the Compressed Gas Assn. be transmitted to those who can really help to ease the tight situation in which our gas industries find themselves today."

Oxyargon Mixture

A new and revolutionary principle that multiples the speed of sigma welding* of stainless and carbon steels has been announced by The Linde Air Products Co., a Division of Union Carbide and Carbon Corp. Unusual results have been obtained by use of a mixture of oxygen in argon as a shielding atmosphere.

Earlier research had established that, for best welding conditions, metal transfer consists of a series of discrete metal droplets propelled at a high velocity. Droplet formation will vary with different metals and for different current densities.

Recent investigations by Linde have shown that the droplet rate particularly on stainless and carbon steels, can be materially increased by the addition of small percentages of oxygen to highly purified argon. Droplet rate in this oxyargon mixture has been as much as 50 times greater than in an atmosphere of pure argon, other conditions being the same.

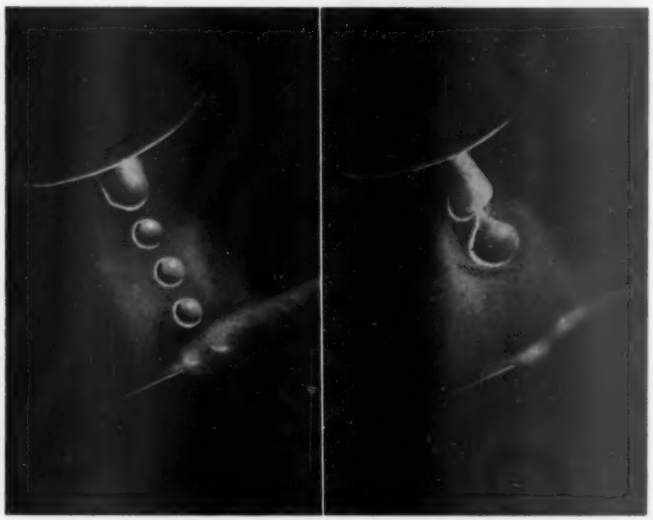
This greatly increased droplet rate, with no change in current density, permits welding at higher speeds without undercutting. Coalescence of the weld metal is improved at increased welding speeds. Overhead welding of stainless steel is made practicable.

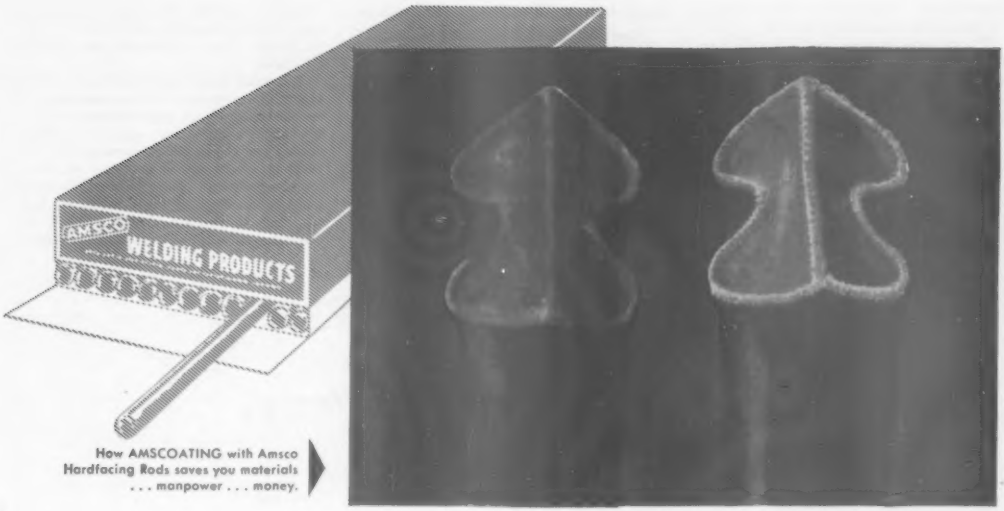
On the other hand, the oxyargon mixture permits welding at lower current densities. This means that larger diameter, more economical rods may be used for a given welding current. If the size rod now available is used, then thinner materials can be welded.

Use of this special argon is expected to expand the application of sigma welding on stainless steel because of improved economy, and ability to perform welding operations not practicable with straight argon. Likewise, on carbon steels, increased applications of sigma welding can be expected as welding speeds can be at least doubled, gas consumption correspondingly reduced and less expensive welding rod used.

The oxygen-argon mixture has been introduced on the market as Linde argon-

* The words "sigma welding" are a generic term, descriptive of the shielded inert gas metal arc process for welding.





How AMSCOATING with Amsco Hardfacing Rods saves you materials . . . manpower . . . money.

Why will ONE of these bits LAST TWICE AS LONG?

AMSCOATING...stands for control of wear by Hardfacing...

Hardfacing rods—and recommendations for their use—are as sound as the manufacturer who makes them. AMSCO has been fighting wear for a half-century—first with Manganese Steel, and later with AMSCO Hardfacing Products.

If you have a problem of wear caused by impact, abrasion, heat or corrosion . . .

Find out how AMSCOATING can save you materials . . . manpower . . . money!

These bits are used by a Southern quarry for drilling blast holes. A combination of limestone and flint causes extreme abrasion—and a real problem of wear. In an attempt to cut replacement costs, labor and down-time, several makes of hardfacing rods were tried, but without much success.

Six years ago these bits were AMSCOATED with an Amsco® rod specially developed for combatting abrasion and impact.

Result? AMSCOATING did a job that had never been done before. The drill bits held their edges longer . . . averaged 60 hours of drilling—between regrinds—instead of 30. Maintenance costs and bit changes were cut in half!

AMSCOATING saves you money in terms of lower maintenance costs, less down-time . . . more production. *The actual on-the-job example cited above is one of the many applications that prove it!* Write today for illustrated catalog describing dollar-saving AMSCO rods . . . and the name of your nearest AMSCO distributor.

AMSCOATING

THE RIGHT WAY TO SAY HARDFACING

Brake Shoe **AMERICAN MANGANESE STEEL DIVISION**

399 EAST 14th STREET • CHICAGO HEIGHTS, ILL.

Other Plants: New Castle, Del., Denver, Oakland, Cal., Los Angeles, St. Louis. In Canada: Joliette Steel Division, Joliette, Que.
Amsco Welding Products distributed in Canada by Canadian Liquid Air Co., Ltd.

sigma grade. Its price will be the same as for Linde argon, standard welding grade.

The artist's drawing on the left is illustrative of the sigma welding arc with Linde argon, sigma grade, while the drawing on the right simulates the arc in an atmosphere of pure argon. The conditions illustrated are for identical current densities and welding rod sizes.

The relative size of the drop of metal being transferred in each case shows that many more, but smaller, drops are formed in the special grade argon atmosphere, thus adding greatly to the inherent stability of the arc under all conditions. During the time of a full cycle of droplet formation in a pure argon atmosphere (right drawing), some 50 droplets will have been deposited in the special grade argon atmosphere (left drawing).

Also illustrated is the fact that the weld bead is generally wider and flatter in the special gas atmosphere than the narrower and higher weld bead in the pure argon atmosphere.

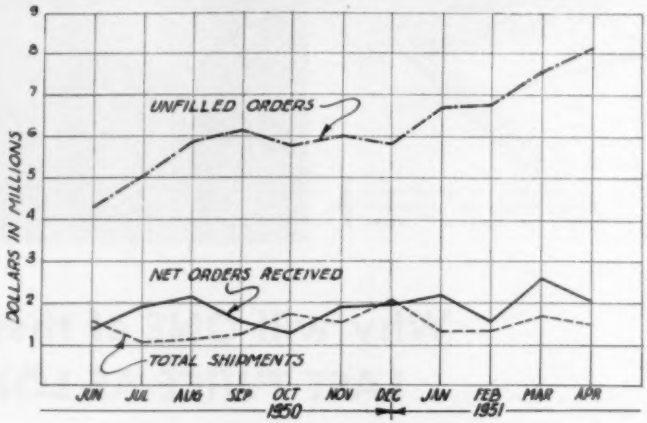
A.S.M. Selects Wilson as Vice-President

At the annual meeting of the Nominating Committee, the American Society for Metals named for vice president, Ralph L. Wilson, Director of Metallurgy, Timken Steel and Tubes Division, Timken Roller Bearing Co. Mr. Wilson is a member of the AMERICAN WELDING SOCIETY and is now completing the second year of a two-year term as SOCIETY Treasurer.

Resistance Welding Manufacturers' Backlog Increasing Monthly

Since December net orders for resistance-welding machines have been running ahead of monthly shipments with the result that the industry's backlog of unfilled orders has increased steadily. According to data compiled by the Resistance Welder Manufacturers Assn., the backlog of unfilled orders of Members is now higher than at any time since pre-Korea. The accompanying graph, showing net orders received, total shipments and unfilled orders on hand, clearly illustrates the present situation.

According to the Association, manufacturers of resistance-welding machines are encountering many aggravating delays in deliveries from their suppliers. While these have not as yet reached serious proportions, they are nevertheless retarding the completion of partly finished machines and the number of such machines now standing on the floors of manufacturers awaiting parts has increased substantially.



National
Carbide

IN THE RED DRUM

EFFICIENT

ECONOMICAL

DEPENDABLE

FOR WELDING and CUTTING

Use National Carbide in the Red Drum

Write us for information as to nearest available stock.

60 E. 42nd St. NATIONAL CARBIDE COMPANY New York 17, N.Y.

A Division of Air Reduction Co., Inc.

A NEW NAME FOR SAFETY
FROM ONE OF AMERICA'S
OLDEST LENS MAKERS!

PENOPTIC

SAFETY LENSES

Announcing a complete line of quality replacement lenses, including flat, 1.25 curve, 6.00 curve and (antiglare) green absorptive lenses.

They offer a high quality of protection, assured by more than a quarter century's experience in precision lens making.

Order them *direct*. Save with safety!

PENNSYLVANIA OPTICAL COMPANY • READING, PA.

Known for Fine Ophthalmic Products Since 1886

**PENOPTIC is the trade name of Pennsylvania Optical Company*

Complete Welding Facilities Provided by New Big Three Plant

Everything needed for the welding industry is provided by the new plant of the Big Three Welding Equipment Co. on an 8-acre tract at 3602 W. 11th St., Houston, Tex., where a main warehouse, repair shop, oxygen plant, carbide and acetylene building and extensive offices have been erected. Not only will welding equipment, accessories and supplies of all types be handled but welding machines will be repaired and rebuilt and oxygen supplied for use in the surrounding territory. An area of nearly 90,000 sq. ft. is under roof and a room in the warehouse provides 6000 sq. ft. of dehumidified storage where 4,000,000 lb. of rods can be stored under ideal humidity conditions that will protect the rod coatings indefinitely.

Oxygen for industries in the immediate vicinity will be furnished in gaseous form through pipelines. New equipment is being installed for shipment of liquid oxygen to the company's other plants in Texas and Oklahoma since the low-temperature liquid oxygen transported in special vessels built onto trucks can be shipped more economically.

The repair shop is equipped for complete rebuilding of welding machines as well as their repair. Many machine parts will be rebuilt and stocked in order to maintain a complete exchange service for customers. Other machines, such as air-compressors and pipe-beveling units, will also be repaired.

The general plan and layout was developed not only to meet the company's present needs but also to provide for anticipated expansion. Big Three Welding Equipment Co. started with a little 18 x 30 ft. rented building in Fort Worth in 1920 where C. K. Rickel, now president of the company, and B. K. Smith, with a part-time helper, began handling welding equipment for Texas industry. Today, when moving into its new Houston plant, the company, with its associated gas plants and other interests, has more than 300 employees and expects to do more than ten million dollars' worth of business during the current year.

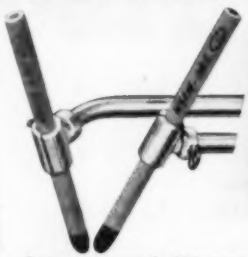
New Big Three Plant

Main Building

Repair Plant to the Left of Main Building

BECKER

KEEN-ARC CARBONS



FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

BECKER BROTHERS CARBON CO.

3450 South 52nd Ave. Cicero 50, Illinois

DC Welder proves itself again!

Schwartz Supply Company

BUILDING MATERIAL AND SPECIALTIES

NEW ORLEANS 19, U.S.A.

November 29, 1950

Gulf Welding Equipment Company,
1133 Magazine St.,
New Orleans 13, La.

Gentlemen:

Several months ago we purchased from you a Westinghouse RA Electric Welder. This is the new type DC Welder with no moving parts except a fan.

We would like to take this occasion to let you know that this machine has been very satisfactory and is all that you promised us it would be. We believe our power saving is at least 40% over what the same capacity motor generator welder would cost us to operate.

With all good wishes, we remain,

Yours very truly
SCHWARTZ SUPPLY COMPANY

BY:

CR: MP

YOU CAN BE SURE... IF IT'S Westinghouse Rectifier Welders

James W. Dunham New President of International Acetylene Assn.

James W. Dunham, Vice-President of National Cylinder Gas Co., Chicago, was elected President of the International Acetylene Assn. at the annual business meeting held during this organization's recent Annual Convention in Montreal, Quebec. Mr. Dunham had served as Vice-President for the year 1950.

F. W. Hench, President, American Oxygen Service Corp., Harrison, N. J., was elected Vice-President of the Assn. E. V. David, Assistant Manager of the Technical Sales Div., Air Reduction Sales Co., New York, was re-elected Treasurer. H. F. Reinhard was re-elected Secretary.

James W. Dunham was born in Danvers, Mass., and received his primary education in the public schools of Brookline, Mass. He studied chemical engineering at Massachusetts Institute of Technology, receiving his B.S. degree in 1926.

Mr. Dunham started his business career as an engineer for the Keith Dunham Co., following his graduation from college. He continued with its successor company, National Cylinder Gas Co., of which he is presently Vice-President, Director, and Chairman of the Executive Committee. He is also a Director of the Midwest Carbide Corp., Tube Turns, Inc., and the Pennsylvania Forge Corp.

Mr. Dunham has devoted many years of his life to the interests of the oxy-acetylene industry, and has taken an active part in the functioning of such organizations as the International Acetylene Assn. and the Compressed Gas Assn.

Westinghouse Teaches Arc Welding Techniques

Welding operators and plant engineers in the Buffalo, N. Y., area are being shown the latest in arc-welding techniques and apparatus at a school currently being run by Westinghouse Electric Corp. Theme of the school is the effective and economical use of available power, labor and materials.

The course will include information accumulated by Westinghouse through its experience as a major user of welding processes, designer of welded structures and manufacturer of welding apparatus.

Started on Monday, May 7th, the course will run for five consecutive Monday evenings, from 7:30 to 9:30 P.M. Sessions include lectures, films or demonstrations, and discussions. They are held in the Westinghouse Buffalo plant.

Chairman for the welding school is F. V. Schilling, supervisor, Arc Welding Application Engineering, Eastern District, Westinghouse Electric Corp. The school program, as announced by Mr. Schilling, includes these lectures by Westinghouse personnel:

"Design for Welding," by C. H. Jennings, engineering manager, Arc Welding Dept.

"Welding Metallurgy," by E. R. Gamberg, engineer, Electrode Dept.

"Arc-Welding Electrodes and Their Applications," by E. H. Turnock, manager, Electrode Dept.

"Arc-Welding Apparatus," by E. F. Steinert, manager, Welding Apparatus Engineering.

"Automatic Arc Welding," by H. J. Unsel, design engineer, Welding Apparatus Engineering.

a 127% dividend!

$36.93 Return for $16.27.

That is what Membership in A.W.S. provides!

In 1950 A.W.S. spent $263,382.41—an average of $36.94 for each of its 7132 registered members.

Those 7132 registered members only paid dues amounting to $116,875.15: an average of $16.27 per member.

Membership dues accounted for but 47% of the Society's income. The Society earned the other 53%, or $146,507.26, from other activities; every one of which benefits each member.

Therefore *each* member gained 127% on his investment; a far higher rate of gain obtainable from any other investment.

Federal Reserve Board and Bureau of Labor Statistics record that-today-durable goods *cost* 99.9%—and non-durable goods *cost* 118.3%—*more* than in 1939.

BUT—AWS membership *costs* the average member *only* 24.7% more than in 1939.

invest in A.W.S.—

—JOIN NOW—

—it pays dividends

River Transportation

Vital river transportation of coal from mines to steel mills and other points in the Pittsburgh industrial area is being improved this spring by the addition of eight new towboats.

The eight vessels, six of which already have been launched, were especially designed for the river coal trade by Dravo Corp. They are powerful 108-ft. craft of welded steel construction throughout. Their normal tows consist of six river barges loaded with 5400 tons of coal. Each towboat can develop 25,000 lb. thrust, or "pushpower."

Three vessels are for Pittsburgh Consolidation Coal Co. and two for Jones & Laughlin Steel Corp. One each is for Crucible Steel Company of Ameica, U. S. Steel Co. and Island Creek Fuel and Transportation Co.

"Assembly line" production is used at Dravo's Neville Island shipyard to construct the vessels.

Diesel-powered, the eight towboats are given more "pushpower" and maneuverability of the installation of Dravo Kort nozzles, steel rings of airfoil cross section that encircle the propellers to feed them larger volumes of water. Approximately 283,000 gal. of water a minute are supplied to each propeller through the Dravo Kort nozzle.

In general, these eight towboats reflect a modern economical approach to river towing operations because they carry more power in smaller, yet highly maneuverable hulls.

The following gives a general description: Length (molded), 108 ft.; beam (molded), 26½ ft.; depth at side, molded to main deck, 9 ft.; draft with ⁷/₈ fuel and supplies, 6½ ft. level keel; and fuel oil capacity, 16,000 gal.

Each welded steel, 108-ft. hull is constructed in three major sections—forward, engine room and stern. These sections are built on specially constructed yard fitting and welding jigs. Prefabricated assemblies from the structural shop are used for the hull sections. Likewise, all other structural parts of the boats are prefabricated.

Hull of each towboat is subdivided by four main transverse watertight, oiltight bulkheads and two longitudinal wing bulkheads which are carried to the main deck. The hull forward is of modified ship form fitted with two substantially constructed towing knees, port and starboard, and one centerline knee built into and forming part of the bow. The hull after is formed to house the two propellers in Dravo Kort nozzles.

Steering ahead is affected with one rudder aft of each propeller. Steering astern is accomplished with two rudders forward of each propeller. The rudders are of the balanced type welded of double ⅜-in. plating with necessary diaphragm plates and nose bars. Two Dravo hydraulic system steering engines operate rams and linkage for the rudders—one system for the flanking rudders and one for the steering rudders. The steering gear system has a 50-gal. accumulator tank and a 200-gal. sump tank. Two variable volume pumps, each driven by a 5 hp. d.-c. motor, are used in the hydraulic system. Rams are controlled by steering levers in the pilot house.

Two air compressors, driven by 5 hp. electric motors, provide compressed air for the vessel. There are three starting air tanks, each 20 in. in outside diameter and 96 in. long.

Propellers are four-bladed high-tensile manganese bronze, 6 ft. in diameter with a mean pitch of 5 ft. 4 in.

Comfortable accommodations are provided on the vessel for an average crew of 13. The steel deckhouse on the main deck contains the engine room, galley, mess room, crew quarters and deck stores.

Officers are quartered in the upper deckhouse (Texas deck) which is located on the forward section of the main deckhouse. The pilot house is installed at the forward end of the upper deckhouse, with a companionway leading to the officers' quarters. Another companionway leads from the hallway in the officers' quarters to the main deckhouse.

There are two showers and toilet facilities on the main deck and one on the upper deck.

The galley is as modern as any kitchen found in a new home. It contains a stainless steel sink, built-in cabinets, a stainless steel liquefied petroleum gas range with

Fig. 1 View of the towboat, Vesta, one of two built for Jones & Laughlin Steel Corp.

Fig. 2 Scene in Dravo's shipyard where the eight towboats were built on an assembly line. In the foreground is the line for subassembly erection and to the right of it is the final assembly line

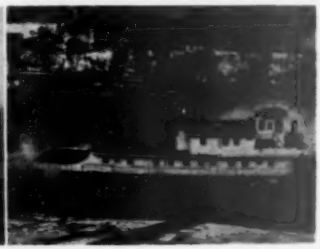


Fig. 3 Launching the towboat, Crucible, built for the Crucible Steel Company of America

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Saxe System Welded Connection Units for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures"

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WELDING & SAFETY EQUIPMENT

FOR OVER 25 YEARS

There is a DOCKSON distributor near you. Name on request.

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LYON Metal Products selects SQUARE D WELDER CONTROL

There's a lot of "beneath-the-surface" quality in Lyon Kitchen Cabinets . . . and spot welding plays a major part in their sturdy construction and beautiful appearance. For consistent quality and continuous production, Lyon specifies Square D resistance welder control.

Simple *Safront* timer construction, using dependable pneumatic timing relays, assures easy inspection and maintenance. *SYNCRO-BREAK* contactors are especially suited for use with production welders which must operate over a wide range of weld times and duty cycles. Synchronized opening of the contact tips eliminates arcing and permits higher current ratings.

Square D also offers electronic contactors and timers for jobs requiring unusually short and precise timing, high welding currents, or high speeds.

Class 8991
Type TCS-10 NEMA 5B
Safront Sequence Weld Timer

Class 8990
Type SCG-2 Size 2W
Syncro-Break Welder
Contactor

NEMA 3B and 5B Timers and Sizes 1W and 2W Contactors have same dimensions

Write for Class 8990 Bulletin 211 and Class 8991 Bulletin 210, Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin

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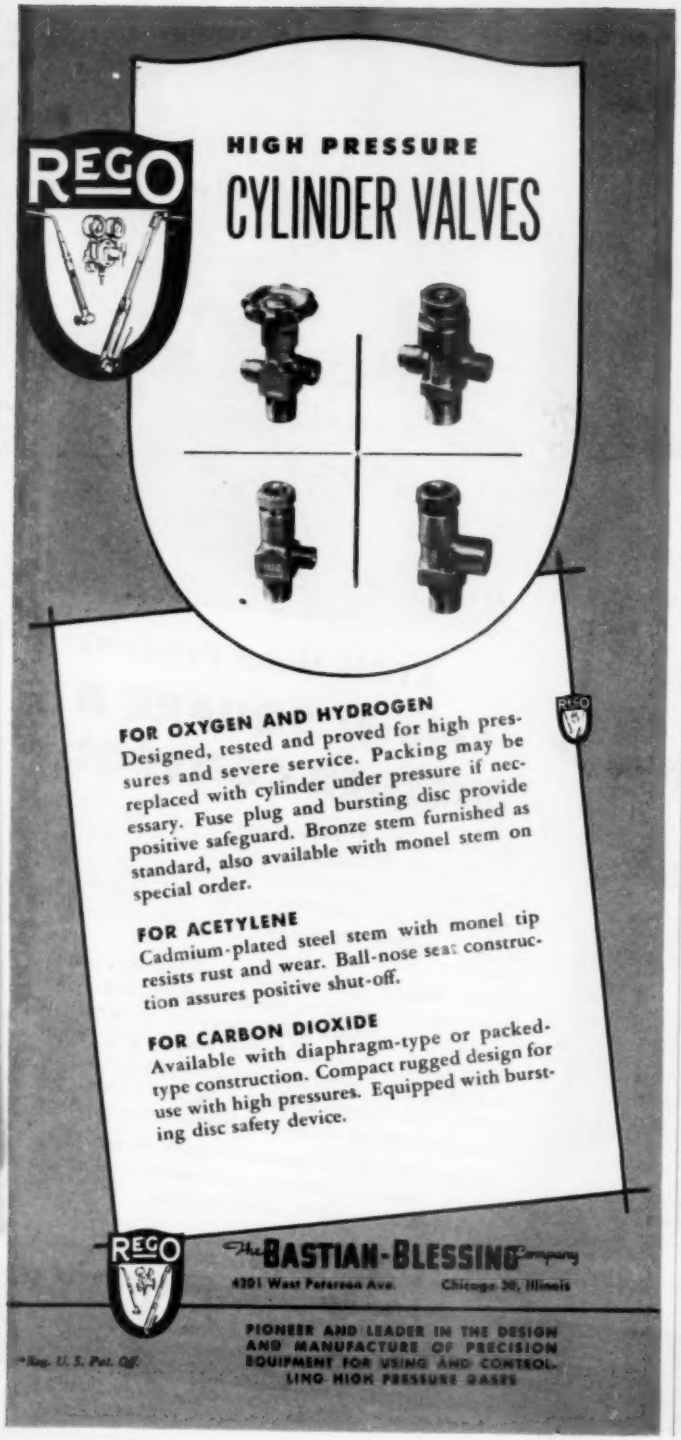
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Available with diaphragm-type or packed-type construction. Compact rugged design for use with high pressures. Equipped with bursting disc safety device.
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exhaust ventilator built into the furred-down ceiling. There is a 16-cu.-ft. food freezer and a 50-cu.-ft. reach-in refrigerator in the galley.

In the mess room adjoining the galley are dining tables and chairs that also can be used for recreation. The lounge, at the forward end of the main deck house, is equipped with leather upholstered furniture.

Heating aboard the vessel is by hot water radiators supplied by an oil-burning welded steel water tube boiler having 1120 sq. ft. of radiation. It is fully automatic.

In the pilot house is a late model radar set for navigation through fog. A sound-powered telephone system is installed between the pilot house and the engine room.

A 16-ft. yawl is carried on the aft end of the boat and there is a derrick for lowering it over the side.

M. Keith Dunham Receives Morehead Medal Posthumously

The 1951 James Turner Morehead Medal of the International Acetylene Assn. has been awarded posthumously to M. Keith Dunham, late President of National Cylinder Gas Co. The award was made to Mr. Dunham in recognition of his inventive pioneering and administrative leadership in the operating, engineering and economic aspects of the oxy-acetylene industry. The Medal was received for his father by James W. Dunham, Vice-President of National Cylinder Gas Co. The presentation was made by A. J. Fausek, President of Modern Engineering Co., St. Louis, Mo., and a past-president of the Association, at the opening session of the Convention of the International Acetylene Association at Hotel Windsor, Montreal, on May 21st.

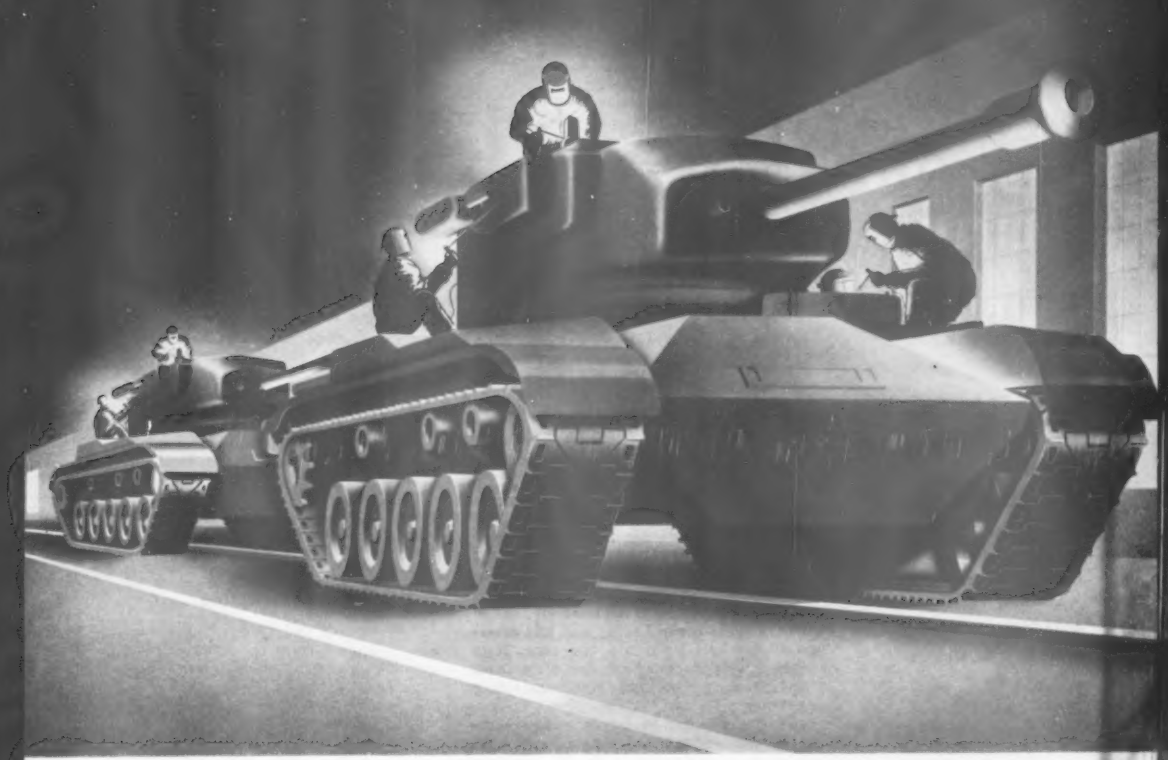
The Morehead Medal is awarded annually by the Association for outstanding working in advancing the industry or the art of producing or utilizing calcium carbide, its derivatives and allied products, the most important of which is the gas, acetylene.

Through the generosity of John Motley Morehead, the yearly award of the Medal has been made possible. The practice of awarding the Medal was established in 1922 to honor his father, James Turner Morehead, who was responsible for the experiments leading, in 1892, to the discovery of the electric furnace method of producing calcium carbide. Since then the Medal has been awarded annually.

M. Keith Dunham was born Oct. 18, 1882, at Brick Ridge, St. John, New Brunswick. He received his education at Danvers High School, Danvers, Mass., and Commercial Business College, Salem, Mass. At the age of 19, he went to work for the Southern Ry., staying with them for seven years.

In 1908, Mr. Dunham became interested in the possibilities of welding and began experiments with various kinds of apparatus and welding procedure. The result was the formation of the Waterhouse Welding Co. in 1911 which was a job welding shop. At the same time, he continued his interest in the manufacture and sale of special types of apparatus, including decarburizing apparatus, particularly

WHERE TANKS ARE BUILT



ARMOR-ARC *is the accepted Electrode*

Armor-Arc B.....307 Lime Coating for DC welding
Armor-Arc C.....307 Lime Coating for AC welding
Armor-Arc MN...307-AC-DC Coating
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Now—YOUR WELDER CAN DO INERT GAS SHIELDED WELDING

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HIGH FREQUENCY ARC STABILIZER

MODEL 13 "MISSING LINK" ARC STABILIZER

- Finger Tip Remote Control at Torch
- Starts Arc Without Contact
- Constant Arc Stabilization
- No Idling Between Welds
- Automatic Gas and Water Control Valves
- Automatic Timed Gas Afterflow
- No Costly Gas Waste
- For AC or DC Welders

Yes, your present welder, AC or DC, can be equipped with the Mid-States "MISSING LINK" Arc Stabilizer for inert gas shielded welding. A compact unit with high frequency generating circuit, gas and water control valves, remote control relay and gas afterflow device—all built into one case. It is equipped with standard gas and water hose fittings, ready for inert gas shielded welding attachments.

The exclusive gas reservoir feature automatically gives selected time afterflow to protect the tungsten electrode after welding arc is broken . . . No electric timer needed . . . no moving parts to adjust or wear out . . . foolproof . . . can also be used for metal arc welding of heavy or thin gauge metals.

There are "Missing Link" Models for 0-300 Amp and 0-600 Amp Welders.

FOR METAL ARC WELDING

"Missing Link" Model 10 is the ideal unit for metal arc welding . . . No pecking or scratching . . . starts arc automatically . . . permits welding of all metals with ease.

REMOTE CONTROL

Small switchette on welding torch is depressed to energize high frequency circuit, start flow of gas and water, and establish welding arc! All stop automatically when arc is broken! Timed gas afterflow, to protect tungsten electrode, is also automatic!

SEE YOUR MID-STATES JOBBER OR WRITE DIRECT FOR INFORMATION COVERING THE COMPLETE LINE OF MID-STATES AC ARC WELDERS AND ACCESSORIES

MID-STATES WELDER MFG. CO.

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in demand for automobile cylinder work during that period.

At the same time, Mr. Dunham had begun the development work on a nonflashing oxyacetylene torch, which utilized the principle of slightly higher acetylene pressure than oxygen pressure. This was a significant advance and was important in promoting the safety and efficiency of medium-pressure acetylene torches.

In 1916, Mr. Dunham became a consulting engineer to the welding industry. His comprehensive book, *Automobile Welding with the Oxy-Acetylene Flame*, was widely read at that time.

On joining the Bastian-Blessing Co. in 1917, he assumed charge of the engineering and sale of oxyacetylene torches and equipment.

In 1921, Mr. Dunham, working independently along a new line, fostered the sale and installation of air liquefaction-type oxygen-producing plants to the smaller companies in the oxyacetylene industry. These plants were imported from Germany. A few years later he foresaw the great demand for welding and the need for prefabricated welding fittings, and he acquired the necessary patent rights to set up a company for production of these fittings. From this beginning, the welding fitting industry has made tremendous strides and from it the present Tube Turns Co. of Louisville, Ky., has grown.

Mr. Dunham was the original founder of National Cylinder Gas Co. which has evolved from the combining of several companies. Death came to Mr. Dunham in September 1940.

Both the father, Mr. Keith Dunham, and his son, James W. Dunham, have been associated in the work of the International Acetylene Assn. for many years.

Film on Grinding

"Grits That Grind," a new Norton Co. color motion picture on abrasives and grinding wheel manufacture, is now ready for immediate showing.

It is a 30-minute, 16-mm. film showing step-by-step manufacturing processes from mining bauxite in Arkansas to the finished product in Worcester: Alundum (aluminum oxide) and Crystolon (silicon carbide) grinding wheels.

This new film is now available free of charge on loan by writing to "Grits That Grind," Norton Co., Worcester 6, Mass. Copies may also be purchased.

National Cylinder Builds Miami Liquefaction Plant

The National Cylinder Gas Co. has begun construction in Miami, Fla., of a liquefaction plant for the production of oxygen and nitrogen. It will be completed in August and will have a capacity of approximately five million cubic feet per month.

NCG now has an acetylene plant in Miami but formerly has supplied the Miami area with oxygen and nitrogen from its Jacksonville plant.

The new Miami facilities will be under the general supervision of G. L. Reynolds, the firm's Florida district manager.

Schilling Co. Organized

Frederick V. Shilling of Buffalo, N. Y., formerly Supervisor, Welding Application Engineering, Westinghouse Electric Corp., has announced the formation of a new sales organization covering Western New York and Northwestern Pennsylvania, The Shilling Co.

Complete lines of arc-welding equipment and supplies; resistance welders and controls; hydraulic pumps; controls and accessories; and specialty tools and fixtures for the metal fabricating industry will be represented.

Mr. Schilling is a member of the AMERICAN WELDING SOCIETY, the American Society for Metals, and is a past chairman of the Niagara Frontier Section, AMERICAN WELDING SOCIETY. His experience includes service as an Industrial Welding Specialist with the War Production Board and as an Aviation Hydraulic Specialist, U. S. Navy, during World War II. He has been connected with welding design, application and sales for more than fifteen years and will be available as a welding consultant to the welding industry. He attended George Washington University, Washington, D. C.

GE Announces New Welding Distributors

Appointment of five new G-E welding distributors to serve New York State, portions of New Jersey and Pennsylvania, Alabama and the Toledo, Ohio, area has been announced by General Electric's Welding Div. at Fitchburg, Mass.

Serving New York State from Poughkeepsie west to Geneva is the Welding Engineering & Equipment Co., Syracuse, N. Y. President of the company is S. Harry Monson, 15-year veteran of the welding business and a member of the AMERICAN WELDING SOCIETY.

Eastern and northern New Jersey, the metropolitan area of New York and Long Island and New York State north as far as Poughkeepsie are being served by the Welding Sales Corp., with offices at Newark. Harry S. Pierce, president of the company, has been in the business for 25 years.

Covering New York State west of Geneva is the Welding Equipment Sales Co., Buffalo. George Cobb, a member of the SOCIETY, who has been in the welding business for 20 years, is president of the company.

The three new G-E welding distributors above take over the sales and services formerly offered by the Welding Engineering Sales Corp. of New York City.

The Alabama Oxygen Co. has been appointed to handle the Birmingham area. Sole independent manufacturer of oxygen and acetylene in the state, the company is the second G-E welding distributor in this region. W. E. Rolls is manager of the firm.

To serve the Toledo, Ohio, area, the Odland Iron Works has been appointed. Fred T. Braithwaite, president of the company, reported that a separate sales organization has been established to handle the G-E welding equipment. Vice-President and General Manager Sam W. Snell, 25-year veteran of the welding business, is a former chairman of the Toledo section of the AMERICAN WELDING SOCIETY.

All five new distributors are authorized to carry a complete line of a.-c., d.-c. inert-arc, and atomic-hydrogen welding equipment as well as mild, low-alloy, hard-surfacing, stainless steel, and new hi-thoria electrodes.

New Administration and Welding School Building Inaugurated by Eutectic

To consolidate and house existing branches of the company scattered in and about the New York metropolitan area, including the general and executive offices, and the new Eutectic Welding Institute (an advanced brazing center for welders), a new, modern Administration Bldg. has been constructed by Eutectic Welding Alloys Corp. at Flushing, N. Y.

The structure covers an acre in the Auburndale section of Flushing adjoining the larger manufacturing plant erected by Eutectic last year.

Over two hundred persons were present at the dedication and inaugural ceremonies. J. P. Hughes Wasserman, father of Eutectic's president and founder, a pioneer of the welding industry for nearly fifty years, came from Switzerland to attend.

Excerpts from Inaugural Speech by Rene D. Wasserman, President

Every industry—automotive, electrical, machinery, mining equipment, bakeries, chemical foundries, etc—is able to save material and labor through the use of welding, or overlaying common metals with high-hardness materials to effect an economy of high-alloy steel. We have been closely connected with this phase of welding, but we have also pioneered in another aspect, which is salvage.

Only the other day I saw a photograph which our engineer, who had returned from a trip to Africa, showed me of railroad cars in Abyssinia which were salvaged after a long period of idleness caused by the lack of spring steel. It is only recently that we have developed an electrode to weld truck and railroad car springs successfully. With this method, the broken springs were soon repaired, a matter of only a few days in fact, and the cars were put back into operation.

Another similar, little known application is, for example, the case of the General Motors plants where especially made huge broaches, costing thousands of dollars each, break. Through the discovery of the proper alloy and proper procedure, a precision-built broach completely heat treated, mind you, can be welded in a few hours and returned to use without further treatment. This method has been so successful that many General Motors plants now have a tool salvage program, enabling them to save thousands and thousands of dollars every week.

Die castings, such as the grille of your car, door handles and other parts which previously were often discarded when broken, can now be saved and made as strong as new through welding. I could give you literally hundreds of examples illustrating how this form of welding saves in the day in defense industries today, as well as in every plant and shop in the country.

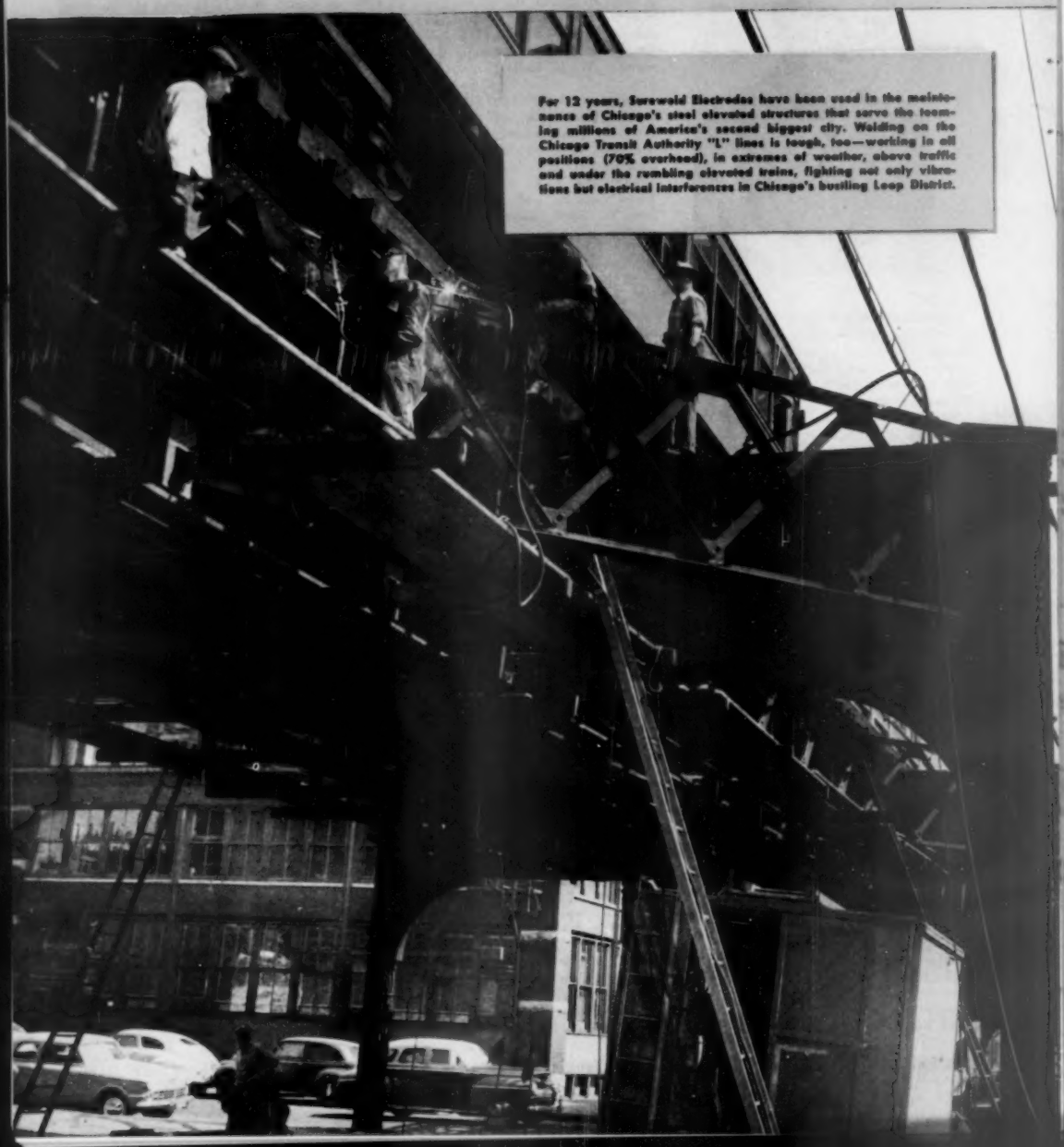
Manufacturers and users of welding have been quick to realize the fact that certain manufacturers recognize the importance not only in producing the best product but also in actively assisting in the proper application and uses of welding. Therefore we are very honored to be called in more and more by leading industries to confer with them on this metal joining problems.

Employment Service Bulletin

Services Available

A-618. Welding Engineer and Supervisor desires position. Eleven years' experience in the welding field, the major portion as a welding inspector in a large shipyard. Familiar with radiography, magnetic particle inspection, preparation of etch, tensile and hardness specimens, operator qualification tests, etc. Worked on research and development of numerous special shape-cutting machines and studs welding. Considerable flame-hardening work. Thirty-four years old. Married, three children. Willing to locate anywhere but prefer West Coast area. Seeking permanent connection with opportunity for advancement.

Wherever you go...



For 12 years, Surewold Electrodes have been used in the maintenance of Chicago's steel elevated structures that serve the teeming millions of America's second biggest city. Welding on the Chicago Transit Authority "L" lines is tough, too—working in all positions (70% overhead), in extremes of weather, above traffic and under the rumbling elevated trains, fighting not only vibrations but electrical interferences in Chicago's bustling Loop District.

IT'S *Sureweld*® FOR SURE, BETTER WELDS!

North, South, East, West—in big industries and small—Sureweld Electrodes are helping welders get the job done faster, better, easier. New users are discovering every day what thousands of old users have known for years—that Sureweld can be depended on for top performance —whatever the welding problem.

Prove it for yourself! Call in an NCG representative or distributor and let him recommend a rod for the job that's giving you the most headaches. You'll soon learn for yourself that Sureweld excels in speed, easy operation, easy slag removal, low spatter loss and excellent bead appearance. You'll cheer Sureweld's uniformly high quality.

NCG®

EVERYTHING FOR WELDING

NCG is recognized as one of the largest organizations of its kind in the world. It operates 73 manufacturing plants within the United States, offers supply and service by a vast network of hundreds of independent NCG distributors and warehouses. For assured satisfaction in your welding and cutting needs . . .

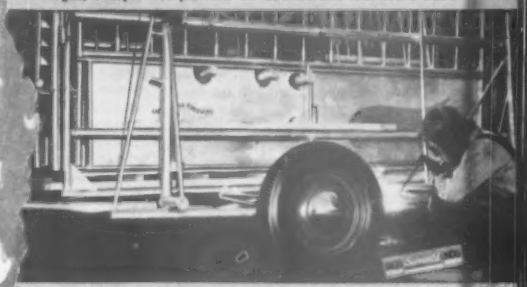
RELY ON NCG

NATIONAL CYLINDER GAS COMPANY

Executive Offices: 840 N. Michigan Ave., Chicago 11, Ill.

Copr. 1951, National Cylinder Gas Co.

"We have used Sureweld Electrodes exclusively for the past six years, and the marked preference of our foremen and welders for Sureweld makes it quite evident that we shall continue to use them 100% in the future," says Jack Frost, vice-president of Wiley Manufacturing Company, Mountville, Pa., manufacturers of floating cranes, steel barges, Wiley Whirleys, concrete buckets and fabricated steel.



"Our choice has always been Sureweld," says L. E. Heldenbrand, President, Heldenbrand & Son Manufacturing Company, Oklahoma City, Okla., manufacturer of "Silver King" products. Sureweld is used in the production of the 3-in-1 Silver King Cattle Chute, requiring 350 welds per finished unit. "Sureweld C fits our need because it is fast, gives good penetration and welds in all positions," says Mr. Heldenbrand.

"We like the clean, even beads deposited by Sureweld B—we think it is the smoothest-running wire we have ever used," says F. E. Collier, owner of Charlotte Ornamental Iron Works, Charlotte, N. C., fabricators of "Trusiube." "We have used NCG services and supplies since we first started in business, and we like the prompt, friendly attention we always get," states Mr. Collier.

NEW LITERATURE

Air Tools

Bulletin No. 38 entitled "Air Tools for the Foundry, Steel Mill, Production Line, Assembly Plant" has been issued by The Rotor Tool Co., 17325 Euclid Ave., Cleveland 12, Ohio.

Rotor's complete line of air tools are illustrated, together with application photos and specifications. These lines of air grinders, drills, hammers, scalers, etc., should be of interest. Prompt attention will be given to readers of THE WELDING JOURNAL who request copy of this catalog.

Health Protection in Welding

The Industrial Health Section of the Metropolitan Life Insurance Co., New York, has issued a thirty-page pamphlet on the above subject. This pamphlet discusses the possible effects of gases and fumes in the welding of various metals and of light and heat rays upon the health of workers engaged in welding operations. It contains suggestions for the protection of welders. This pamphlet is available on request.

Protective Equipment

A four-page circular on protective equipment for welders is available at no charge from Willson Products, Inc., Reading, Pa., manufacturers of personal safety equipment.

The circular describes and illustrates a wide range of eye protective devices for both gas and arc welding, and includes product information on respiratory protection for welders. Accessories such as rubber mask padding for goggles, and the Weld-Aid lens for welders who wear bifocal glasses are also described.

A full page is devoted to various types of filter glass and includes a selector chart of types and shades for different welding operations.

Stud Welding

K S M Products, Inc., Merchantville, N. J., has just published a new booklet containing helpful information for engineers, purchasing agents and welding superintendents concerned with applying studs and other fasteners to steel surfaces.

This booklet is packed with data on how stud welding eliminates drilling, tapping and hand welding. It shows the fundamental operating principles of the stud-welding process, and typical applications. It also contains information for K S M studs and stud-welding equipment.

Copies are available by writing for Catalog 451 to K S M Products, Inc. Merchantville 8, N. J.

All-State Folder

A four-page folder just issued by All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y., describes three specially packaged All-State low-temperature brazing alloys and fluxes now widely used for intermittent work and infrequent jobs requiring supplies that are inherently too expensive to be handled in bulk.

These alloys, one of which contains 45% of silver, are available in tubes of transparent, shatterproof plastic designed for maintenance outfits and repair kits as a place to keep the alloy safe from loss, indiscriminate use and the annoyance of grease and dirt such as interfere with making good joints, the importance of which expands as defense needs more frequently require repair instead of replacement.

Copies of the folder may be obtained from any All-State distributor.

Metco News

The current issue of *Metco News* describes and illustrates how you can stretch your "Maintenance and Operating Supplies" dollars under NPA Regulation No. 4. For instance, one of a long list of successful applications is the experience that a Pennsylvania oil company had with pump rods. The material pumped is crude oil "bottoms" which contains quantities of grit, sand, dirt, etc. The original cold-drawn steel rods usually lasted for about 48 hr. To increase this service life they tried metallizing the 25-ft. bearing length with a special self-bonding molybdenum wire. At the last report, over two months after the first metallized rod had been put into service, it was still in excellent condition, operating 24 hr. a day.

Send for your copy of *Metco News*, Volume 5, No. 8, Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Accident Prevention

The graph of industrial accident rates in this country is a ski-slope picture—injury rates sliding downhill fast through the 1920's, evening off on fairly level ground through the 1930's to the mid 1940's, a modest dip since World War II.

What will start the rate downhill fast again? We think the answer is to convince small business that accident prevention pays off.

Big business learned that lesson many years ago.

So today, more than two-thirds of all industrial injuries occur in businesses with fewer than 100 workers!

As the opening gun in a stepped-up effort to interest small business in the economic and social benefits of accident prevention, the National Safety Council of 425 North Michigan Ave., Chicago 11, Illinois, is distributing a booklet, "Safety Pays the Smaller Business."

The initial distribution will be through insurance companies. However, if our readers are unable to obtain a copy from their carriers, single copies will be available from the Council without charge.

Electronic Motor and Welder Controls

Written by George M. Chute, Application Engineer, General Electric Co., Detroit, Mich., this book offers the kind of practical assistance that can mean quicker and better job performance for the man who must select, install or service electronic controls for motors and resistance welders. It gives specific and detailed explanations of the circuit operation of the tube-operated equipment found in the two major groups of motor and resistance-welding control . . . starts each chapter with an introduction to a complete electronic equipment and then splits it into its component circuits for individual treatment . . . pinpoints each operation with simple descriptions and clearly drawn diagrams.

You will find that this book presents improved electrical circuits, with a great variety of closed-cycle motor-control systems, and that it considers the stable operation of such motor systems. Among the topics covered are: basic welding controls, sequence timers, synchronous timing and combinations, seam-welding controls, position controls, and speed control of d.-c. motors.

Among hundreds of kinds of electronic control used in industry today, two stand out—controls for motors and controls for resistance welders. And, from this book's descriptions and diagrams, you get a full understanding of the circuit operation of the equipments found in these two groups . . . an understanding that can mean better selection, installation and servicing of electronic control equipment. Price $6.50.

Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 18, N. Y.

New Standards

Ninety-nine new and revised American Standards are listed for the first time in the latest edition of the Price List of American Standards just published by the American Standards Assn., 70 E. 45th St., New York, N. Y.

This list contains more than 1180 standard specifications, methods of test and symbols and abbreviations in civil engineering and construction, mechanical engineering, electrical engineering, safety codes, ferrous and nonferrous materials and metallurgy, rubber, textiles, mining pulp and paper, photography, motion pictures and gas burning appliances.

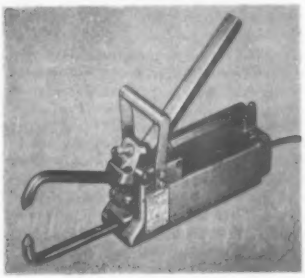
The 26-page list of American Standards (May 1951) can be obtained from the American Standards Assn., 70 E. 45th St., New York 17, N. Y., without charge.

NEW PRODUCTS

Heavy-Duty Spot Welder

A heavy-duty model of the Sureweld Portable Spot Welder with a welding range up to $^{3}/_{16}$ in. combined thickness on mild and stainless steel, or two pieces of 16-gage galvanized metal, is announced by the National Cylinder Gas Co., Chicago. This exceeds by 50% the $^{1}/_{8}$ in. capacity of the standard 110- and 220-v. models.

Operating on 220 v., single-phase, 50/60 cycle a.-c., the new model is suitable for spot welding in factories, sheet metal shops or anywhere that sheet metal is fabricated or repaired.



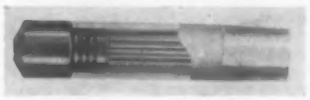
All models are operated with a toggle-action lever that locks the tongs on the work while the weld is being made. This assures tight, strong welds without muscular strain by the operator. The lever can be adjusted for any thickness of metal in the range.

A variety of interchangeable tongs, with replaceable tips, adapt the welder to any job, especially in "hard-to-get-at" places.

The heavy-duty model weighs 31 lb., the two standard models 25 lb. each. Prices, without tongs, are $138 and $98, respectively.

Cap Electrode

P. R. Mallory & Co., Inc., Indianapolis, has announced another resistance-welding innovation—the Mallory "Nu-Wrinkle Cap" Electrodes. While it has many advantageous features, basically the Mallory "Nu-Wrinkle Cap" Electrode materially reduces electrode costs, without any sacrifice in performance, and conserves critical copper alloy.



This cap electrode consists of a reusable shank and a replaceable cap, the cap being relatively small and inexpensive in comparison with the conventional one-piece electrode. When the welding face of the cap electrode is no longer serviceable, it is necessary only to replace the small, inexpensive Mallory "Nu-Wrinkle Cap"—still using the same shank.

A corrugated skirt provides positive electrical and thermal contact with the shank, while the fluted water hole in the shank assures maximum cooling efficiency. The design of the cap skirt and shank shocket provides positive alignment.

Because of its unique design, the Mallory "Nu-Wrinkle Cap" Electrode is a readily replaceable insert for resistance welding dies. It is available in all standard Mallory nose shapes—in Elkaloy A and Mallory 3 metals.

Electrode Holder

Cam-Lok Co., manufacturers of Welding Cable Connectors for the past five years was recently acquired by Empire Products, Inc., of Cincinnati, Ohio. Coincidental with the acquisition of all assets of the Cam-Lok Co., Empire Products, Inc., announced the building of a modern manufacturing plant in Rossmoyne, Ohio. Henceforth, the welding products company will be known as Cam-Lok, Division of Empire Products. Cam-Lok will continue the manufacture of its well-established welding cable connectors and has

announced the addition of a new electrode holder and solder and mechanical type terminal connectors.

The new electrode holder is designed to eliminate waste motion and unnecessary fatigue in arc welding. The handle is the right size for the operator's hand. Loading trigger is operated with one hand, without fumbling. Trigger works easily, yet jaws grip electrodes firmly. The position of the jaws eliminates rod bending and makes welding in cramped spaces easier.

The Cam-Lok Electrode Holder is fully insulated with tough, laminated material. There are no coil springs in the operating mechanism which is completely enclosed and protected by the insulation. The Cam-Lok Holder is available for immediate shipment in three sizes: Heavy Duty (500 amps.), General Purpose (300 amp.) and Light Duty (200 amp.).

Additional information, including literature on the Cam-Lok Electrode Holder and other Cam-Lok welding accessories, is available on request to the manufacturer, Cam-Lok Div., Empire Products, Inc., P. O. Box 98B, Cincinnati 36, Ohio.

New Brazing Rod

Phosphor bronze arc welding such as is often required in general maintenance work and repair is generally characterized by pitting and porosity. In many applications this is of no consequence. But where a smooth surface is essential as in the case of bearings and parts having to be corrosion-resistant, pitting and porosity is extremely undesirable. In many such applications a nice smooth face is now being obtained by "surface washing" with All-State No. 23 Phosphor-Copper-Silver Brazing Rod. This rod, "washed" on with a neutral or excess-acetylene flame or with a Prest-O-Lite torch or oxy-city gas flame, has such a low working temperature (1270° F.) and is so fluid when molten that it readily flows into and bonds every crack and pit within the area of its application. No. 21 Brazaloy Flux is used in applying this rod.

All-State Welding alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y.

Cover Lens

A new plastic cover lens that reduces fogging and is more durable than regular glass and plastic cover lenses is announced by American Optical Co., Safety Products Sales Div., Southbridge, Mass.

Developed to protect more costly filter lenses from hot metal spatter and scratches, the new lens is formed so that the center portion is raised. The air space created between the two lenses automatically reduces fogging to a minimum. The use of fiber washers is also unnecessary with this new construction.

The new plastic lens will remain pitfree longer than glass and resists fusion of hot metals and spatter. Also, the shock-absorbing acetate cushions upon impact and does not crack.

The new cover lenses may be obtained from American Optical Co. branches located in principal industrial cities.

Chemalloy Metal

Chemalloy is a new metal alloy suitable for dry bearings, precision casting, fluxless welding and to draw off heat from other metals. It is an alloy of metals and chemicals produced by bringing together an alloy of molten metal plus an alloying of a wet chemical mass. It defies rust, resists corrosion, works without lubricants in moving machines or parts, remains cool while being lathe-turned and can be made at a reasonable cost from either scrap or virgin materials.

The ability to combine a wet chemical mass with a molten mass free from explosive hazards is a proprietary technique. It is a development of Chemalloy Asso-

ciates, Santee, Calif. Once the original metal is made, it can be melted or remelted like ordinary metals. The molecular structure of the ingredients are changed with the modified chemical properties thereafter being substantially retained in a solid state.

Welding Rod Without the Use of Flux: This has been successfully used in welding aluminum and may possibly work with other metals. It may be applied directly to the aluminum heated beyond the Chemalloy melting point (400–450° C.). Chemalloy welds pot metal and vice-versa. In a chemalloy-potmetal weld, it is very difficult to find the weld when the weld cross section is sawed open.

Oxyacetylene Process Quickly Removes Surface Metal and Burned-In Sand

Sand encrustations, fins, pads, chaplets or chill nails and other forms of excess metal can be removed from castings quickly, easily and economically by means of an oxyacetylene method recently developed by The Linde Air Products Co., a Division of Union Carbon Corp.

The new process, called power-washing, utilizes a special OXWELD FSC-1 Blowpipe, equipped with external powder-washing attachment. With this apparatus, an iron-rich powder is fed through oxyacetylene preheat flames into a low-velocity oxygen stream where it burns and produces superheated liquid iron oxide. Heat from the combustion of the powder and from the slag simplifies and speeds the removal of metal and metal-sand mixtures. Wherever the powder-fed flame is directed against a casting, the metal surface is brought quickly to kindling temperature, and then it is oxidized and blown away by the oxygen stream.

After powder-washing, the surfaces of castings are left smooth, clean and to close tolerance. There is no undercutting, and no torn metal.

The washing nozzle, used with the FSC-1 Blowpipe, has a large center hole through which the low-velocity oxygen stream is discharged. Around the large hole is a ring of 10 preheat flame ports. The powder is discharged from a flat tube above the nozzle.

A pneumatic dispenser supplies the power. Compressed air, regulated to 6 lb. per square inch, carries the powder through a separate hose to the powder attachment mounted on the blowpipe. Other equipment used with the FSC-1, such as regulators, accessories and oxygen and acetylene supply, is the same as used with ordinary hand-cutting blowpipes.

The washing blowpipe is relatively simple to operate. Anyone familiar with hand-cutting equipment can learn to use it quickly. Even inexperienced operators can learn the technique in a short time.

The biggest factor in powder-washing technique is manipulation of the blowpipe, since compressed air and oxygen pressures remain the same for almost all jobs. The Blowpipe is moved from side to side across the surface of the casting, in oscillations up to approximately 4 in. wide, depending upon the width of the surface being washed. The nozzle face is held about 2½ to 3 in. from the reaction zone, and the oxygen stream is directed against the casting face at a 20 to 35° angle.

Flat or uneven surfaces can be powder-washed with equal ease. The powder-washing reaction works readily into places that are hard to reach with other equipment. Encrusted sand, which blunts the points of air hammer chisels, is removed easily and cleanly by powder-washing. Defects can be gouged out by the washing process, and excess metal in repair welds can be quickly washed away.

The powder-washing process saves time and money in finishing castings. It can be used easily wherever excess metal has to be removed, and it will do the removal job with speed and economy.

Braze-Clad Steel Strip Simplifies Silver Brazing

To simplify the brazing of steel joints and at the same time guarantee their unqualified perfection, the American Silver Co., Inc., of Flushing, N. Y., is now manufacturing Braze-Clad low-carbon steel strip.

This steel strip is clad with silver brazing alloy on one or both sides, in any thickness ratio and melting range, to suit the requirements of each particular brazing application.

The steel surface being precoated evenly with the brazing alloy, no preplacements are necessary, and every joint is assured of a complete and uniform spread of alloy.

Braze-Clad joint surfaces, being prediffused with the silver brazing alloy, eliminate the need of such preplacements as wire rings, sheet washers and blanks, and thus reduce considerably the tedious cleaning and fluxing operations before brazing. The prediffusion also controls the flow of the metal during brazing and eliminates the necessity of cleaning off any overflow or unwanted fillets.

Therefore, whenever a brazed joint must be perfect—where it must stand a severe pressure test—where preplacements are difficult and slow—or where a joint design is too intricate or inaccessible for conventional brazing, Braze-Clad steel will prove most useful. It is available in all thicknesses down to 0.005 in. and in any width up to 4 in.

In addition to steel, the company also makes Braze-Clad nonferrous metals such as copper, brass, nickel-silver, nickel, beryllim-copper and silver.

Fig. 1 — An OXWELD washing blowpipe with powder attachment, developed by The Linde Air Products Co., is being used to remove excess metal and encrusted sand from a casting.

Plastic Cover Plate

A new plastic cover plate which provides greater protection for welding helmet windows is announced by American Optical Co., Southbridge, Mass. It is made from special thermosetting plastic, a material that is superior in performance to thermoplastics for cover plates, according to the company.

The new plate is clear, hard and almost colorless, possessing surfaces comparable in smoothness, luster and chemical resistance to polished plate glass. It is more resistant to pitting than glass, will not discolor under ordinary welding conditions, and will not peel, crack, blister or shrink in service.

The new plastic cover plate will last longer than glass and gives up to 1000 hr of service, the company states.

Plastic Cover Lens

A new plastic cover lens for welding helmets and welding goggles has been introduced by Willson Products, Inc., manufacturers of personal safety equipment at Reading, Pa.

The new cover lens is known as "Spatterproof" and is available in 2 x 4 1/2 in. and 50-mm. round sizes, 0.040 in. thick.

The new lens is made of a long-service resistant plastic that will withstand pitting for much longer periods than either plain glass or coated cover glass.

Portable Spot Welder Speeds On-the-Job Repairs

A precision-built portable resistance spot welder is now available for on-the-job repair of Inconel and stainless steel foil and screen and for making alterations required by changes in design. Known as the HIT-KIT (No. 45-21144), this compact spot welder was developed by the H. I. Thompson Co. for the repair and alteration of REFRASIL Insulating Blankets, but the versatility of the unit makes possible its wide use in many other applications where on-the-job repairs or changes must be made.

Operation is by trigger-type switch. By contacting both electrodes to the foil surface and inducing current by operating the trigger, foil is securely welded in place. Welder is equipped with leads 9 ft. in length, attached to welding tips and operates on 110 a. c. Power consumption is low, assuring economical operation.

The HIT-KIT is simple and sturdy in construction and requires a minimum of maintenance. The standard model includes tools and materials necessary for many types of repair. Foil thicknesses up to 0.004 and screen wire diameters up to 0.020 can be easily and securely spot welded.

For further details write or call W. E. Benke, Sales Manager, The H. I. Thompson Co., 1733 Cordova St., Los Angeles 7, Calif.

Join Forces to Develop New Industrial X-Ray Process

Commercial development of xeroradiography—a new process that may greatly reduce the use of films and darkrooms in industrial X-ray work—is the object of a joint program just launched by three organizations: The Haloid Co. of Rochester, N. Y., Battelle Memorial Institute, Columbus, Ohio, and General Electric X-Ray Corp., Milwaukee, Wis.

Xeroradiography is expected to make X-ray inspection faster and more economical so that it can be utilized in many more industrial fields for the first time, particularly in smaller foundries, machine shops, general metal-working firms and many other types of plants. It may also provide a tool of considerable value in the inspection of ordnance and other war material, and has possibilities for application in the field of medical diagnosis.

Xeroradiography (pronounced "Zeroradiography") is a fast, low-cost, dry, direct-positive process for producing X-ray images. It is electrostatic, rather than chemical in nature. Re-usable plates and low-cost powders take the place of chemicals and films used in conventional radiography. In less than two minutes, with a minimum of effort, an industrial inspector would secure a "shadow" picture similar to that on an X-ray negative, showing the internal condition of his product.

Xeroradiography has definite advantages over rapid film development processes in that it is entirely free of chemicals and employs re-usable plates. Another advantage is that neither the image nor the xerographic plate is affected by any type of radiation including atomic radiation.

Xeroradiography is being developed at Battelle under Haloid-Battelle sponsorship. General Electrix X-ray is cooperating in the project and will market the equipment, when perfected, through its nation-wide network of district offices. The new process is an outgrowth of xerography, a method for producing fast, low-cost copies of anything written, printed or drawn, using light rather than X-rays. Xerography, already commercially available, is a product of The Haloid Co.

Silicon-Free, Flux-Coated Aluminum Welding Alloys

Flux-coated aluminum welding rods for oxyacetylene and oxyhydrogen welding have been released by Eutectic Welding Alloys Corp., 172nd St. and Northern Blvd., Flushing, N. Y.

For architectural structures and many other applications where an anodized silicon bearing welding rod has always shown an objectionable dark weld, Eutectic's new EutecRod 22FC is said to provide a base metal matching solution since corrosion resistance and color, as well as physical properties of the weld, are said to closely match the aluminum. The flux coating is "low melting" to provide for minimum heat application and once melted, flows in a transparent pool, permitting the welder to easily watch the progress of the work while eliminating the "stoppages" that occur when a rod with separate flux is used.

New EutecRod 22FC is manufactured in 1/8 and 3/16 in. diameters. Full details and specifications are available on request from Dept. T18, Eutectic Welding Alloys Corp., 172nd St. and Northern Blvd., Flushing, N. Y.

Welding Metallurgy

First published in 1940, this book has had several printings and has been distributed all over the world. To bring up to date, Mr. G. E. Linnert has prepared an extensive revision so that the new edition has 505 pages—150 pages more than the first edition. Many new illustrations have been added to bring the total to 203.

$2.50 per copy. Order through American Welding Society, 33 West 39 Street, New York 18, N. Y.

SECTION ACTIVITIES

prepared by C. M. O'Leary

Anthony Wayne

The final regular meeting for 1951 of the Anthony Wayne Section was held on May 18th at the Lunz Barn, Elmhurst Gardens off Sand Point Road, Ft. Wayne, Ind. Music was furnished by Johnny Wright's Orchestra for both round and square dancing. Over 70 members and guests enjoyed the evening. Attendance prizes were given to persons holding lucky numbers. Refreshments were served by Brudi's Catering Service. The following officers were announced for the 1915–52 season: *Chairman*—Harry M. Johnson, Wayne Welding Supply Co.; *1st Vice-Chairman*—Russell F. McNutt, Sutton Garten Co.; *2nd Vice-Chairman*—Virgil Beck, Beck Welding Works; *Secretary*—K. H. Zimmerman, American Steel Dredge Co.; *Treasurer*—Gerald Springer, International Harvester Co.

Arizona

The Arizona Section held its regular monthly meeting on Wednesday, May 16th, at the Phoenix Technical School. It was a dinner meeting with 43 members and guests attending. Results of the annual election were announced and indicated the following as the new officers and executive committee: *Chairman*—Arthur Tesmer, Salt River Power District; *1st Vice-Chairman*—J. August Rau, Allison Steel Mfg. Co.; *2nd Vice-Chairman*—William Garland, Consolidated Western Steel; *Secretary*—Walter E. Riley, Riley and Foltz, Consulting Engineers; *Treasurer*—F. Morris Aspey, Consolidated Western Steel Corp.; *Executive Committee*—Charles Carlson, Edward Thomas, Robert Phares, Charles Fogwell, B. M. Boan, Gil Dye, William Fischer, Ralph Hoffman.

A very interesting technical meeting was presented by the School at 8 P.M. Two technicolor sound films, one, "The Magic Wand of Industry," by The Lincoln Electric Co.; the other, "Vertical Welding," by the General Electric Co. were shown first, then the group went to the Welding Laboratory where demonstrations were given of the arc, proper and improper arc lengths, too fast bead and too slow a bead. Various students were observed while welding and several members and guests tried their hand at welding. All agreed the meeting was very successful and were impressed by the magnitude of operations at the School.

Chattanooga

The final meeting and annual party of the Chattanooga Section was held on Friday, June 1st. The party, which consisted of a fish fry, was held on the grounds of the Chattanooga Rod & Gun Club on Chickamauga Lake. The members in charge of arranging the party did an excellent job and as a result, everyone present seemed to prefer this type of function to the usual dinner meeting for the annual party.

The election of officers was held during the past month with results as follows: *Chairman*—George T. Tepley; *Vice-Chairman*—C. T. Ward; *Secretary-Treasurer*—James W. Koch; *Members-at-Large* (for 2 years)—P. O. Beach, J. W. O'Neal, Sr.; (for 1 year)—Fain W. Ingram, Roy Mitcham; *Past-Chairman*—W. L. Herbst.

Cleveland

The 12th Annual Welding Symposium of the Cleveland Section at Hotel Allerton, May 11, 1951, made history. It was the largest of these events for attendance with 493 dinner guests and 500 total registrations for the technical program.

Even the weather helped (in a negative sort of way) to make this a most successful event. The program was such a powerful drawing card that it took the most inclement symposium weather in symposium history to put just enough brake on the attendance to result in just a comfortable number.

This year was a first for a formal educational exhibit. Exhibitors went all out in providing displays of great value to the welding profession. Exhibit space was provided without cost to the exhibitor. About 40 exhibitors availed themselves of the opportunity to show the part welding plays in our industrial economy. Under the careful screening of educational exhibit chairman Hubert Hinkel of Williams & Co., the entire exhibit room was filled with a most fascinating display of welding know-how samples, welding procedures and testing and inspection methods.

The array of technical papers in the afternoon were by users of welding and were down-to-earth presentations of everyday welding problems and how they were solved. Chairman of the technical session was Lew Gilbert, Editor of *Industry and Welding*.

The technical session was replete with papers covering the gamut of welding. Production or repetitive welding was discussed by Sherman T. Heald in his paper on "New Developments in Inert-Arc and Resistance Welding." Mr. Heald, Assistant Chief Electrical Engineer, Republic Steel Corp., Steel & Tubes Division, is directly responsible for electrical and experimental work in all phases of induction heating, nondestructive testing and development of equipment for automatic welding.

It would be difficult to assess the relative value of welding as a means of preventing production stoppages. This application of welding would probably be evaluated at least on the same level as welding applied as a powerful productive tool. James Hyslop, President, The Hanna Coal Co., presented a paper on "Maintenance Welding Around-the-Clock." Maintenance welding falls into three channels: inspection for preventative welding, preventative welding and emergency welding. Both preventative and emergency welding are restorative welding, the first before and the second after failure.

Ross Yarrow, Superintendent of Consolidated Iron & Steel Manufacturing Co., spoke on "Latest Trends in Structural Welding." Structural is the behemoth, tailor-made, nonrepetitive welding job. It comprises the bulk of job shop welding and falls into the main categories of field welding and shop welding. Mr. Yarrow discussed structural fabrication from considerations of design, layout, jigs, fixtures, fit-up, distortion problems, inspection and erection.

All three speakers are members of the American Welding Society and are users of welding. As users, the intimate experience of daily contact with welding on the front line or application front, was thus the keynote of the sessions.

Louis Seltzer, crusading Editor of the Cleveland *Press*, presided as toastmaster over the evening program. Mr. Seltzer formally dedicated the 12th Annual Cleveland Section 1951 Symposium to A. E. Gibson, President of Wellman Engineering Co.

Dedication of the symposium is the Cleveland Section's opportunity each year to recognize particular achievement of one of its members in the Society and the industry. Mr. Gibson did yeoman service in the interests of the Cleveland Section for many years. He was Chairman of the Cleveland Section for the period 1933–36 and A.W.S. national president for the 1936–37 term. Mr. Seltzer presented Mr. Gibson with a pen and pencil desk set in the name of the Cleveland Section. A bronze plate engraved with the particulars of the dedication formed part of the onyx base of the set.

The high light of the symposium was an address by United States Senator Karl E. Mundt of South Dakota. Senator Mundt gave a stirring, inspirational address on "Americanism" in which he disproved the theory that the mind can only absorb as much as the seat can endure. After almost an hour and a half of exposing the

machinations of communist workings and castigating the great American public for forsaking the rugged individualism of previous generations for the dangerous alternative of letting Uncle Sam do it, Mundt was enthusiastically applauded by an audience on its feet. Karl Mundt's oration made the headlines in all the major Cleveland newspapers.

The most significant remark in this speech was the reference to an experience at a communist cell meeting in Denver in 1933. At this time the senator was occupied as an educator and farmer and had no thought of devoting himself to politics. The Denver meeting (dealing with communistic promotions through the means of overriding states rights by dividing the country into seven areas, each area to be a Federal electrical power monopoly) was so fantastic, the Senator laughed it off as a scheme not to be taken seriously. No one realizes his error as the result of hindsight better than he does.

A feature of the annual symposium is the Cleveland Section's May publication. The publication for the 12th symposium was a 96-page directory, buyers' guide and symposium editorial matter. The Section's members are listed alphabetically and by company affiliations with addresses, titles and phone numbers.

A.W.S. national board meeting was held in Cleveland, May 10th, and most of the national officers and directors remained for the symposium. The Cleveland Section is always glad to rub shoulders with A.W.S. top brass and thoroughly enjoys having old friends (among which were Pierce, Plummer, Jefferson, Mooney, Magrath, Crowe and many others) with us.

Credit is due to many Cleveland Section workers for the excellent work that put this affair over. A few of the many were Cal Wyss, Section Chairman; Jack Jarms, Symposium Chairman; Lew Gilbert, publicity assistant and Technical Chairman; Hubert Hinkel, educational exhibits; Clayton Herrick, advertising; Bob Kriz, ticket sales; Otto Borneman, reception; Ed Scott, arrangements.

A smooth functioning affair of this magnitude just isn't possible without the services of competent ladies. The Cleveland Section is fortunate for the genius of artist Jo Ann Barr for the art work and the secretarial staff, Sylvia Jarms, Nancy Flinta and Marge Owen.

Colorado

Howard N. Simms of Black, Sivalls & Bryson, Inc., gave an extemporaneous talk at the May 15th meeting of the Colorado Section held in Denver, on the subject, "Problems in Modern Day Welding." This was an excellent presentation.

Columbus

Annual Meeting and Installation of Officers was held on May 18th at a dinner meeting at the Riverside Restaurant at Columbus, Ohio. Entertainment was provided and a film showing the Marion Power Shovels was well received.

Dallas

Speaker at the May 9th meeting held in the Auditorium of the Lone Star Gas Co. was Don Rasmussen whose subject was, "New Applications of Low Melting Nonfusion Welding Filler Metals." Mr. Rasmussen is well acquainted with his subject and his lecture was well received.

Dayton

The Dayton Section held its May meeting on the 18th at the Dayton Engineers Club. The meeting was started with a colored movie on the Canadian Rocky Mountains. The movie was excellent and gave a lot of the members a bad case of wanderlust.

The technical session was a talk by Leslie S. McPhee, Welding Engineer, Whiting Corp., Harvey, Ill. Mr. McPhee talked on the Welding of Special Machinery. He had a great many slides illustrating the tremendous variety of products and sizes of equipment made by the Whiting Corp. The problems encountered in the construction of these various devices were explained by Mr. McPhee together with the methods used in reaching a solution. The meeting was closed with the serving of refreshments.

Hartford

Final meeting of the 1950–51 season was held on May 11th at the Light House Inn, New London, with members and their wives attending. Double lobster dinners and large steaks were the main course with large shrimp cocktails for the appetizer course. Dinner and music were enjoyed until 11:30 P.M.

Officers for 1951–52 are as follows: *Chairman*—Frank J. Wallace, Windsor, Conn.; *Vice-Chairman*—Stafford H. Lacey, Auto Battery & Electric Co.; *Secretary*—John K. Light, Hartford, Conn.; *Treasurer*—Clinton E. Swift, Woodbury, Conn.; *Chairman, Membership Committee*—Stephen A. Zane, Manchester, Conn.; *Chairman, Program Committee*—Richard S. Studzinski, The State Welding Co.; *Technical Representative*—John W. Mortimer, Manchester, Conn.

Houston

The May 10th dinner meeting of the Houston Section was held at the Ben Milam Hotel, Houston, Tex., with an attendance of 58 at dinner and 63 at the meeting. Speaker at the technical session was D. H. Rasmussen of the Eutectic Welding Alloys Corp., whose subject was "New Application of New Low Melting Nonfusion Welding Filler Metals."

A film, "Fishing in Mexico," was shown before the meeting.

The Section reports that they had 699 people present at nine meetings, whereas, last year there were only 407 present at the same number of meetings. The Section is proud of the good meetings they have had this year.

Indiana

A tour of the Indianapolis plant of the Western Electric Co. was held on April 27th, with 130 attending. Dinner was served in the Cafeteria of the plant. The tour covered the entire plant and lasted one hour.

The May meeting was held on the 25th at Buckley's Restaurant, Cumberland, Ind., with an attendance of 48 at the dinner and meeting. R. E. Stoffel, Materials and Processes Representative, Air Materiel Command, Indianapolis Sub Office of the Dayton P.F.O., gave a good extemporaneous talk.

Lehigh Valley Annual Meeting and Ladies Night. Left to right: L. P. Elly, Chairman; R. D. Stout, Vice Chairman; J. R. Fairhurst, Past Jr. Chairman.

Kansas City

The new officers elected for 1951–52 by the Kansas City, Mo., Section were announced as follows at the May 17th dinner meeting held at Fred Harvey's, Union Station: *Chairman*—M. L. Powers, Kansas City, Mo.; *Vice-Chairman*—A. G. Hedstrom, Kansas City Structural Steel Co.; *Secretary*—J. M. Payne, Butler Mfg. Co.; *Treasurer*—R. A. Olson, Butler Mfg. Co.; *Program Chairman*—Joe Frick, Air Reduction Sales Co.; *Membership Chairman*—G. G. Demees, Westinghouse Electric Corp.; *Publicity Chairman*—E. D. Anderson, The Lincoln Electric Co.; *Directors*—P. D. Blake, L. L. Cramer, D. E. McCormick.

Les Powers introduced the speaker for the evening, Howard Simms, who spoke on the Problems in Modern Day Welding. Mr. Simms very ably discussed the properties of the weld metal and heat zones of welded joints for various types of steels. Slides accompanied his talk.

Three delegates, Chairman Les Powers, Secretary Joe Payne and Program Chairman Joe Frick, were elected to attend the annual mid-southern district meeting to be held in St. Louis on July 14th. Vice-Chairman A. G. Hedstrom was elected an an alternate.

The meetings for the coming season will continue to be held on the third Thursday of each month in the Pine Room at Fred Harvey's. The price for the dinners will be $2.60.

Lehigh Valley

The Lehigh Valley Section held its annual meeting and Ladies Night on Saturday, May 5th, at the Hotel Bethlehem, Bethlehem, Pa. J. R. Fairhurst, Chairman, presided at a short business meeting at which time the following officers were installed for the 1951–52 season: *Chairman*—L. P. Elly, Bethlehem Steel Co.; *Vice-Chairman*—R. D. Stout, Lehigh University; *Secretary-Treasurer*—R. E. Somers, Bethlehem Steel Co.; *Past Jr. Chairman*—J. R. Fairhurst, Ingersoll-Rand Co. Installed as *Directors* for three years: Vance P. Edwardes, Ingersoll-Rand Co., and Carl E. Schleicher, Easton Car & Construction Co.

A square dancing demonstration under the direction of Hugh and Reita Graham followed the business session.

Refreshments and both square and modern dancing were enjoyed by approximately 60 members and guests.

Michiana

The Michiana Section held its final meeting of the 1950–51 season on May 17th with a combined business and social session at the Chain-O'-Lakes Conservation Club near South Bend, Ind.

Officers were elected for the following year as follows: *Chairman*—George Mittler, Mittler Welding Supply Co.; *Vice-Chairman*—George Fetherston, Bendix Products Division; *Secretary-Treasurer*—W. G. Fassnacht, Bendix Products Division; *Executive Committee*—Glen Farrington, Henry Wheeler, H. E. Kellogg. *Holdover Executive Committeemen are:* Donald Kyler, William Wishart, A. B. White.

Following the business meeting, a general sociable evening was enjoyed with a number of door prizes, gifts of the vendors of this area being distributed by means of a bingo game.

New Jersey

The final meeting of the 1950–51 season was held Tuesday, May 15th, at the Essex House Hotel, Newark, N. J. Walter Begerow, Chairman, presided. Ricardo Muniz, General Manager of the Television Receiver Manufacturing Division, Allen B. Dumont Laboratories, Inc., Passaic, N. J., was the guest speaker of the evening. The talk consisted of a general description of television from both the equipment and operating viewpoint.

The officers and new members of the Executive Committee for the 1951–52 season are as follows: *Chairman*—Frank Yurasko, Standard Oil Development Co.; *Vice-Chairman*—Fred O. Bodine, Midwest Piping & Supply Co.; *Secretary*—Nick F. Kiernan, Metal & Thermit Corp.; *Treasurer*—Ken Koopman, Linde Air Products. New members of Executive Committee: E. W. Evanson, Ford Pollock, Forde Simms, Einar Iverson.

Saturday, September 15th, has been set as the date for the annual picnic to be held at "The Pines," Metuchen, N. J.

The winner of the free dinner for the September meeting was Frank Stanchra of Linde Air Products.

New York

The following officers have been elected by the New York Section for 1951–52: *Chairman*—A. M. Setapen, Handy & Harman; *1st Vice-Chairman*—H. R. Clauser, Materials & Methods; *2nd Vice-Chairman*—S. T. Walter, Air Reduction Sales Co.; *Secretary-Treasurer*—E. W. Axthelm.

Pascagoula

The Pascagoula Section held its regular monthly meeting at the Pascagoula Country Club, Wednesday, May 30th. John F. Bryan, Chairman, presided.

The principal speaker was W. F. Appelton, who spoke on "Some Recent Developments of Welding in Modern Structures." Mr. Appelton is chief structural engineer for Irby Bros. Machinery and Iron Works, Gulfport, Miss.

Problem of welding acceptance in building and bridge construction were discussed in length. Mr. Appelton presented interesting research information on welding concrete reinforcement.

Peoria

Annual business meeting and election of officers was held by the Peoria Section on May 16th at Wheeler's Chicken Dinners. A movie, "Building for the Nation," was shown.

The following officers were elected: *Chairman*—M. Packer, Peoria, Ill.; *Vice-Chairman*—K. Purcell, Peoria, Ill.; *Treasurer*—J. Hanley, Peoria, Ill.; *Secretary*—D. Stine, Peoria, Ill.; *Executive Committee*—C. Wimmer, L. O'Day, D. Batton, J. Brown, G. Deemy, J. Ricca.

Portland

The seventh meeting of the current season of the Portland Section was held Tuesday night, April 17th. An informal dinner was enjoyed in a private dining room of the Galley Restaurant.

The Mixermobile Co. of Portland presented a 30-minute sound movie on the "Towermobile," a portable cement mixing and handling plant.

A short business meeting was held to appoint a nominating committee.

After the business meeting the group of 31 persons were guests of the Willamette Iron and Steel Co. for a plant visit. The group adjourned at 10:00 P.M.

The eighth meeting of the season was held at the Mallory Hotel, Friday, May 25th.

A short business meeting followed an enjoyable dinner. After the business meeting E. H. Weil presented the speaker of the evening, Harold Howland, Industrial X-Ray Engineers, Seattle, Wash.

A 35-minute sound movie was shown on the "Inter-Provincial Pipe Line" through the courtesy of the Bechtel Corp.

The speaker discussed the problems and techniques involved in the use of X-rays for field inspection of pipe-line welds.

After a question-and-answer period, the 32 members adjourned at 10 P.M.

Rochester

The Rochester Section was host to the Niagara Frontier and Syracuse Sections for a "Battle of the Sections" and buffet lunch on April 23rd at the Century Sweet Shop.

The Niagara Frontier carried off the laurels with Rochester second and Syracuse third. The questions and answers covered a wide range of subjects and proved to be very interesting and educational. Bill Conley did a splendid job as Master of Ceremonies.

The Section was pleased to see the nice turnout of guests from out-of-town Sections, Charles H. Jennings, 1st Vice-President of the A.W.S., being one of these from Buffalo, N. Y.

Salt Lake City

A double program was scheduled for the May 10th meeting held in The Seagull Room of the Temple Square Hotel, Salt Lake City, Utah.

First speaker was John B. Ross of Handy & Harman. His subject, "Silver Brazing on the Production Line," was illustrated by a colored and sound movie entitled, "Production Silver Brazing."

Second speaker was Charles Robinson of the Air Reduction Co., who presented an illustrated talk on the process known as "Aircomatic."

Both speakers were very good.

The April meeting was held on the 12th at The Seagull Room, Temple Square Hotel, Salt Lake City, Utah.

Speaker at the technical session was M. W. Crossett of the Development and

Research Division of the International Nickel Co. Mr. Crossett's subject was "Welding Low Nickel Alloy Steels of the ASTM A-203, and Low Alloy High Strength Type." Forrest Allen of the International Nickel Co. talked briefly on their program with accredited Engineering Colleges.

San Francisco

The following officers have been elected by the San Francisco Section for 1951–52: *Chairman*—Wm. F. Ajello, Berkeley, Calif.; *1st Vice-Chairman*—John S. O'Neill, Jr., California Steel Products Co.; *2nd Vice-Chairman*—E. Paul DeGarmo, University of California; *Secretary*—Justin M. Roach, National Welding Equipment Co.; *Treasurer*—E. W. Bartz, Westinghouse Electric Corp.

Susquehanna Valley

The following officers have been elected by the Susquehanna Valley Section for 1951–52: *Chairman*—Stanley R. Bunn, Luzerne, Pa.; *Vice-Chairman*—Harry Swepston, Commercial Gas Corp.; *Secretary*—John Carleton, Berwick, Pa.; *Treasurer*—Robert Schweyer, Berwick, Pa.

Washington

The Washington Section held its annual banquet dinner at the Club 400 on April 24th with an attendance of 98 members and guests.

H. W. Pierce, President of the A.W.S., brought greetings and discussed the current and future activities of national headquarters, which were of interest to all members.

Also present were two past-presidents, O. B. J. Fraser and H. O. Hill, and District Vice-President A. G. Bissell, and Maryland Section Chairman Dr. G. E. Claussen.

The evening's activities started off with cocktails followed by dinner, with an appetizing menu.

Chairman E. M. MacCutcheon introduced the incoming officers, after which Mr. Fraser made a few comments.

The meeting was turned over to A. G. Bissell who presented a straight pin to the past-chairman in lieu of a pin that was ordered to be presented at a later date.

The rest of the evening was taken up with a floor show which was highlighted by the hula dancer getting six men from the audience and dressing them up as hula dancers and having them perform as a student class in the art of hula dancing.

The great success of the meeting should be attributed to the incoming chairman, William P. Roberts, Jr., who made all entertainment arrangements, etc.

Western Michigan

The following officers and executive committee were elected at the May 28th meeting of the Western Michigan Section: *Chairman*—R. E. Kemp; *1st Vice-Chairman*—R. Kline; *2nd Vice-Chairman*—Herb Knape; *Secretary*—Gordon L. Hill; *Treasurer*—Chet Voorhorst; *Executive Committee* (for two years)—Wm. McClellan, E. Anderson, D. Brachen, C. Van Loo; (for one year)—H. D. Hoffmyer, D. LaDue, G. Hickock, P. Wagner, L. Harris.

The 1950–51 season was a very successful one for the Western Michigan Section. The attendance at the dinners and lectures averaged between 70 and 80 and as high as 125. The Section reports they had very interesting speakers at each meeting. Each was a specialist in his line and every phase of welding was covered.

There was no March 1951 meeting, with all efforts being concentrated on the Annual Spring Welding Symposium held in the auditorium of the Public Museum on Friday, April 13th, under the direction of Robert E. Kline.

The symposium was an all-day meeting with a banquet in the evening. The banquet was held at the Park Congregational Church which was attended by 82. Chalk sketches were given by Don Daverman of the American Seating Co., and the main event of the evening was colored slides of the Pacific Northwest, shown by Peter Price, local patent attorney.

The May 28th meeting was addressed by Wm. F. Carr of Lear, Inc., whose subject was "The Automatic Pilot and the Guided Missile."

Wichita

A buffet supper and a guided inspection tour through the Tweco Products Co. plant with the majority of processes in operation during the tour were enjoyed on May 14th.

Howard N. Simms of Black, Sivalls and Bryson, Inc., Kansas City, Mo., presented an extemporaneous talk on the "Problems in Modern Day Welding."

Officers for the coming year were introduced.

LIST OF NEW MEMBERS

May 1 to May 31, 1951

ARIZONA
d'Allemand, E. W. (B)

ATLANTA
Roper, Lawrence J. (B)

BOSTON
Tracy, Lawrence J. (B)

BRIDGEPORT
Sullivan, Edward L. (B)

CHICAGO
Babbitt, B. J. (A)
Belz, Alfred A., Jr. (C)
Muschler, William G. (C)
Palmer, W. Leroy (B)

CLEVELAND
Jessen, N. C. (B)

COLORADO
Hooper, W. D. (B)

DALLAS
Scott, Donald G. (D)

DAYTON
Baird, David (C)
Bruns, Walter G. (C)
Dundon, William E. (B)
Osweiler, Paul L. (B)
Wilson, Geoffrey D. (C)

DETROIT
Blazina, Frank R. (C)
Darin, Ernest (B)

HAWAII
Carpenter, B. P. (C)

HOUSTON
Karr, Milton (B)
Pearson, Jack (B)

KANSAS CITY
Houghton, M. J. (B)
Moore, A. R. (B)

LOS ANGELES
Thomas, J. D. (C)

MILWAUKEE
Willecke, G. K. (B)
Wilson, J. C., Jr. (C)

NEW JERSEY
Bigg, Alfred (C)
Brown, George (B)
Stuyck, Maurice L. (B)

NEW YORK
Gross, Albert (B)
Lesser, John (B)
Osborn, Max R. (C)
Punt, William R. (C)
Thompson, Arthur (B)

NIAGARA FRONTIER
Miess, William W. (B)
Parsons, Charles A. (B)
Rudnick, Harry (B)

NORTHERN NEW YORK
Riedinger, Alan (C)

OKLAHOMA CITY
Adams, C. E. (B)
Bolay, Robert J. (D)
Elliott, William (D)
Lunsford, Delbert E. (D)
Murphy, Malcom, Jr. (B)
Schrader, Louis E. (D)
Stewart, Lowry L. (C)
Tibesar, Edward (B)

PASCAGOULA
Dressel, Noel T., Jr. (C)

PEORIA
Bilyeu, George W. (C)
Gregory, David C. (C)

PHILADELPHIA
Kent, Walter E. (B)
Krystkiewicz, J. J. (C)
Oechsle, Robert W. (B)

PITTSBURGH
Gillespie, J. W. (B)
Kowallis, John (B)

PORTLAND
Hewitt, H. H., Jr. (B)

ROCHESTER
Lass, Oscar (C)

SAGINAW VALLEY
Sommerfield, Donald L. (B)
Tupes, Robert (B)

ST. LOUIS
Baker, Arthur E. (B)
Katz, Jay B. (B)

SUSQUEHANNA VALLEY
Witkowski, Henry P. (C)

WASHINGTON
Henderson, D. B., Cmdr. (C)

WICHITA
Hargrove, Sanford L. (B)
Sutterfield, James S. (C)

YORK-CENTRAL PA.
Lutes, William L. (C)

Not in Sections

Rigole, Girard (B)
Rowley, Kenneth (C)
Yamauchi, Shumpei (B)

Members Reclassified
During the month of May

KANSAS CITY
Cramer, L. L. (C to B)

PHILADELPHIA
Childs, John N., Jr. (C to B)

WASHINGTON
Ingram, Harry L., Jr. (C to B)

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,549,868—Brazing Machine—John R. Vickery, York, Pa., assignor to Aircraft Marine Products Inc., Harrisburg, Pa., a corporation of New Jersey.

This patented brazing machine includes a rotary carrier for having articles to be brazed associated therewith. A heater is provided for heating the articles above brazing temperature, and a reciprocating pawl means is provided for feeding a brazing strip. A guide is associated with the heating position for guiding the brazing strip into the path of the article which is to be brazed while a feeler arm is in the path of the article when approaching the heating position. A movable guide holds the pawl normally out of strip-feeding engagement and it is connected to the feeler to be moved out of its normal position when the feeler is moved by an article.

2,550,284—Welded Journal Box—John Mikulak, Nescopeck, John A. Sober, Bloomsburg, and Edwin B. Sult, Berwick, Pa., assignors to American Car and Foundry Co., New York, N. Y., a corporation of New Jersey.

A specialized type of a journal box is disclosed in and covered by this patent.

2,550,495—Gas Blanketed Arc Welding—Frank J. Pilia, Springfield, N. J., assignor, by mesne assignments, to Union Carbide and Carbon Corp., a corporation of New York.

Pilia's apparatus for arc welding metal includes means for directing an electrode toward the metal and means for advancing a nozzle into contact with the metal to surround an area concentric with an electrode while spacing the electrode from the metal. A valve controls flow of gas to the nozzle to fill the space between the electrode and the nozzle while a timer connects with the valve for turning on electric welding current to the electrode holder for automatically striking an arc between the electrode and the area of the metal concentric with the electrode at a predetermined time interval after the supply of gas has been turned on.

2,550,512—Brazing Process—James N. Woolrich, Erie, Pa., assignor to General Electric Co., a corporation of New York.

A special brazing process for joining metal tubing to a sheet is disclosed in the patent and includes the steps of placing the tubing in contact with the metal sheet and applying to the tubing and sheet a clamp made from brazing material and which has a curved section conforming to the shape of the tube and a flattened portion extending along the surface of the metal sheet and contacting both the tubing and the metal sheet. The clamp is spot welded to the sheet and thereafter the total assembly is heated to fuse the brazing material comprising the clamp to braze the tubing and metal sheet together thereby.

2,550,641—Method of and Apparatus for Welding—Isaac Harter, Beaver, Pa., assignor to The Babcock & Wilcox Co., Rickleigh, N. J., a corporation of New Jersey.

This patent relates to a method of electric-arc-fusion welding wherein a groove is formed along the seam to be welded and simultaneously a plurality of metal-fusing electric arcs are maintained uniformly distributed throughout the entire length of the seam. Weld metal is continuously supplied to each of the arcs while they are reciprocated longitudinally of the seam with the amplitude of reciprocation being of the order of the longitudinal spacing of the arcs. This fills the entire groove uniformly with weld metal at such a rate that the entire body of deposited metal will cool substantially as a unit.

2,550,710—Electrical Welding Apparatus—Howard I. Morris, San Marcos, Calif., assignor by direct and mesne assignments, of one-third to Harvey O. Yoder, Lakewood, Ohio, and one-third to Douglas O. Yoder, Bay Village, Ohio, and Mildred Yoder Kanzenbach, Lakewood, Ohio.

This patent relates to apparatus in which an electrically conductive shaft is mounted for rotation and two welding electrodes are mounted on the shaft and rotate therewith, one electrode being electrically connected to the shaft and the other being insulated therefrom. The apparatus includes transformer means with three primary windings and three secondary windings carried by and rotating with the shaft. A radial flange is provided on the shaft and electrically connects thereto. Said flange is electrically connected with the mid-points of the secondary winding, while six rectifying elements are mounted symmetrically about the shaft and rotate therewith. Other means electrically connect the insulated electrode to the six terminals of similar polarity of the rectifying elements, and separate electrical connections are provided to connect the remaining terminals of the rectifying elements to the terminals of the secondary windings.

2,550,711—Electrical Welding Apparatus—Howard I. Morris, San Marcos, Calif., assignor by direct and mesne assignments of one-third to Harvey O. Yoder, Lakewood, Ohio, and one-third to Douglas O. Yoder, Bay Village, Ohio, and Mildred Yoder Kanzenbach, Lakewood, Ohio.

This patent relates to welding apparatus wherein a rotable support is positioned on a frame with one part of this support being made of electrical conducting material for providing an electrical connection to an electrode mounted on the support. A separate conductor on the support is insulated from the conducting material and adapted to be connected to a separate electrode on the support. A multiphase transformer is provided and its primary coils are connected to an a. c. supply on

"By switching to ANACONDA **828 Welding Rod,** we cut welding time 10 per cent . . . get smoother welds . . . less distortion."

Boiler Erection & Repair Co. operator braze-welding strut into tubular steel assembly with 1/8" ANACONDA 828 Nickel Silver Welding Rod.

"Look at these units," continued Mr. William Raiguel, Plant Supt., Boiler Erection & Repair Company, Philadelphia, Pa. "They're fabricated from 1½-inch, 16-gage carbon steel tubing. Each unit requires six butt welds—about 28 linear inches of weld. The finished units are designed to be part of a heavy-duty farm machine, and every weld must be dependably strong.

"After trying various welding methods and rods we found that by using an acetylene torch with vapor flux and ANACONDA 828 Nickel Silver Welding Rod we get faster, smoother, stronger welds than with any other combination. The low melting point and free-flowing quality of ANACONDA 828 Rod make for faster work and smoother welds that need no finishing. And the low temperature, of course, causes less distortion of the work and reduces the straightening needed."

Braze welding with ANACONDA Welding Rods may cut your production time, cut your costs, improve your products. Your ANACONDA Welding Rod Distributor can help select the right rod. Or write for Publication B-13 to The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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Boiler Erection & Repair Co. operator braze-welding yoke members into position with 1/8" ANACONDA 828 Nickel Silver Welding Rod. No finishing of the weld is required.

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the support. Electrical connections are also provided between the conducting material on the support and the secondary coils for each phase of the transformer and they also connect to such coils midway of the terminals thereof. Unidirectional electronic rectifying means are provided on the support and electrically connected to each of the terminals and between same and the separate conductor.

2,550,743—Method of Welding Brake Beams—Loren L. Whitney, Hammond, Inc., assignor to American Steel Foundries, Chicago, Ill., a corporation of New Jersey.

Whitney's welding method includes the step of depositing an elongated layer of weld metal along the adjoining edges of electrically conductive workpieces by making a pass therealong with a fusible electrode while striking an arc between the electrode and one of the workpieces to melt the electrode. Next the electrode is held stationary while breaking the arc for a period of time less than that required for the weld metal to solidify. Then a reverse pass is made over the layer while striking an arc between the electrode and one of the workpieces and this last-mentioned arc is broken for a period of time less than that required for the weld metal to solidify. Finally the electrode is held stationary at the center of the layer while striking an arc between the electrode and one of the workpieces to deposit a reservoir of molten metal at the center of the layer.

2,550,965—Apparatus for Resistance Welding Fins to the Interior Surfaces of Tubes—John W. Brown, Jr., Lakewood, Ohio, assignor to Brown Fintube Co., Elyria, Ohio, a corporation of Ohio.

This patent relates to apparatus for welding a strip of material to the inside surface of a tubular member in a direction extending generally longitudinally thereof. The apparatus comprises two oppositely disposed electrodes for engaging the exterior of the tubular member on opposite sides thereof and an elongated conductor member is provided for sliding longitudinally within the tubular member and lying on a diameter of same. Such elongated conductor member has a narrow edge adapted to engage the strip of material substantially only along the line of the intended weld. The conductor member has a width at the time the welding operation is carried out which, together with the thickness of the strip, exceeds the normal internal diameter of the tubular member to hold the tubular member outwardly from its normal shape on one diameter thereof.

2,551,244—Means and Method of Bonding Metals—Jesse H. Clark, Walter Grahn and Linus P. Overend, Chicago, and Herschel R. Cole, Glenview, Ill., assignors to Diebraze Corp., Chicago, Ill., a corporation of Illinois.

This patent covers apparatus for the bending and bonding of two sheet-metal blanks, one of corrosion-resistant metal and the other of nonferrous metal and it includes a press that has two coacting die blocks each of aluminum bronze having opposed pressure-applying and heat-transmitting surfaces. The die blocks have means for heating them to a high temperature and a current-flow-resistant contact plate is carried by one die block for engaging the nonengaging ferrous metal blank, and means are provided for advancing one heated die block toward the other to subject the two blanks to heat and pressure when placed therebetween. At least one of the blanks carries a coating of solder and flux is located between the blanks.

2,551,484—Metal Cask or Tank with Belt Weld—Delos J. Branning, Pittsburgh, Pa., assignor to National Tube Co., a corporation of New Jersey.

Branning's patented container comprises a pair of generally cup-shaped sheet-metal sections that are connected by a spigot joint between two relatively telescoped sections of the sheet-metal section. A continuous belt of weld metal is deposited in a groove formed at the joint between adjacent exposed edges of the sheet-metal section. A continuous circumferential zone also is welded adjacent and merging into the continuous belt of weld metal, in which zone the contacting surfaces of the metal section are fused together.

2,552,104-5-6—Aluminum Welding Fluxes—Mike A. Miller and Warren E. Haupin, New Kensington, Pa., assignors to Aluminum Company of America, Pittsburgh, Pa., a corporation of Pennsylvania.

These patents cover special aluminum fluxes composed of varying quantities of nonhygroscopic salts. The materials included in these various fluxes include varying quantities of sodium chloride, potassium chloride, lithium fluoride, aluminum fluoride and a small quantity of alkaline earth sulfate.

2,552,176—Electrode for Cutting and Welding Under Water—Werner Hummitzsch, Kapfenberg, Austria, assignor to Gebr. Bohler & Co., Aktiengesellschaft, Vienna, Austria.

This special electrode is useful for both welding and cutting under water by varying the applied current thereto. The electrode includes a cored wire having compounds ionizable in the electric arc as the core material. The core comprises about 1 to 10% of the cross section of the combined wire and core, and the wire is coated with a mixture of mineral oxides and ferroalloys. The complete electrode is protected by an outer coating of a water-resistant and an electrically insulating varnish.

2,552,468—Process for the Electric Welding of Tubes and the Like—Wilhelmus H. Vosters, Geleen, Netherlands, assignor to De Directie van de Staatsmijnen in Limburg, handelend voor en namens den Staat der Nederlands.

This process relates to the joining of conductive members by butt welding and it includes the steps of forming the edge of one member to present a continuous bevel substantially across the edge and forming the edge of the second member to present a bevel extending only a portion over the face of the said edge. The remaining portion of the second-mentioned edge remains substantially unbeveled. The edges of the members are placed in an approximate butt relationship with the bevels diverging in the same direction. Thereafter the members are welded together and the unbeveled portion of the second member permits liquid weld metal to fuse between such edge and the continuously beveled edge.

2,553,132—Weld Rod Coatings—Arthur T. Cape and Charles V. Foerster, Canton, Ohio, assignors to Coast Metals Inc., Canton, Ohio, a corporation of Delaware.

The patented weld rod coating comprises an alloy containing a metal of the iron group and having a coating thereon which contains graphite. The particles of graphite which pass through a standard 325 mesh screen constitute less than 40% of the total graphite in the coating.

2,553,499—Welding Method—Harold J. Graham, Highland Park, Mich., assignor to Graham Mfg. Corp., Detroit, Mich., a corporation of Michigan.

Graham's welding method relates to the welding of a stud or wire to a surface and it includes the step of shaping one end of the stud with a tip of essentially uneven surface for defining a contact cross section appreciably smaller than the cross section of the stud proper. This tip is covered with a breakable and insulating head which is then contacted with the uneven surface. Voltage is applied to the stud and the surface and pressure is applied to the stud sufficient to disintegrate the head so that the contact area becomes ionized to form an arc prior to full metallic contact of the stud and the surface.

2,552,514—Machine for Inductively Welding Seamed Tubing—Claude A. Bowlus, Detroit, Mich.

This inductive heating apparatus includes means for positioning a workpiece, and means for subjecting the workpiece while so held to the rapid approach and withdrawal motions of a successive series of magnetic fields. This means comprises a rotatable armature having a plurality of magnetic poles arranged around the periphery thereof for successive arcuate movement past the surface of the workpiece. Means also are provided for rotating the armature at a speed so that the poles traverse the workpiece in rapid succession.

WELDING RESEARCH COUNCIL

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Supplement to The Welding Journal, July, 1951

Interpretive Report on Box Girders and Small Specimens

Structures made of steels which are not relatively notch sensitive at low temperatures are able better to sustain loads at such low temperatures than those which are made of notch-sensitive steels

by LaMotte Grover, E. M. MacCutcheon, W. S. Pellini, W. Spraragen and J. Vasta

IN DECEMBER 1944, as the result of a number of meetings of a subcommittee, a program was developed which was briefly entitled "Box Girder Flexural Tests" to study the effect of residual stresses and multidirectional constraint on the behavior of welded structures under external load. It is necessary to repeat the objectives because in such a long program of research, the original objectives are changed in the process of carrying out the program. After a number of years it is difficult to separate the knowledge acquired during the conduct of the test program from that which may have existed before the program was started. The program[1] as originally published in the December 1944 issue of the *Welding Research Supplement* included the following statements:

"One of the AMERICAN WELDING SOCIETY's committees has voiced its opinion that so-called 'reaction' stresses due to severe restraint, or an accumulation of shrinkage from a number of welds under severe restraint, may add general residual stresses to an extent that would be serious.

"Experience shows that most welded structures have given satisfactory service despite these residual stresses. Research indicates, and it is generally agreed, that if ductile behavior, or plastic flow can take place, locally, such stresses become ironed out by mechanical stress relief, and thus become innocuous.

"The important question is therefore, 'Under what conditions may residual stresses become important and serious?' "

The purpose in broad terms was to answer this question with respect to behavior of a structure in service.

Subsequently the main objective was definitized as follows: To determine the effect of a combination of high residual stresses with severe constraint against ductile behavior, upon the capacity of a structural member for resisting rupture under external load. There was particular interest in this behavior at the lowest service temperatures likely to be encountered by a structure out in the open, such as a ship at sea, a railway bridge or a highway bridge.

A secondary objective was to determine the extent of deformation which occurs when the member is subjected to continually increased loading, with the load relaxed between increments of loading. This was thought to be especially significant in view of the fact that some structural failures in ships, bridges, etc., have occurred under comparatively small loads subsequent to a much heavier loading.

The box girder type of specimen (Fig. 1) was selected

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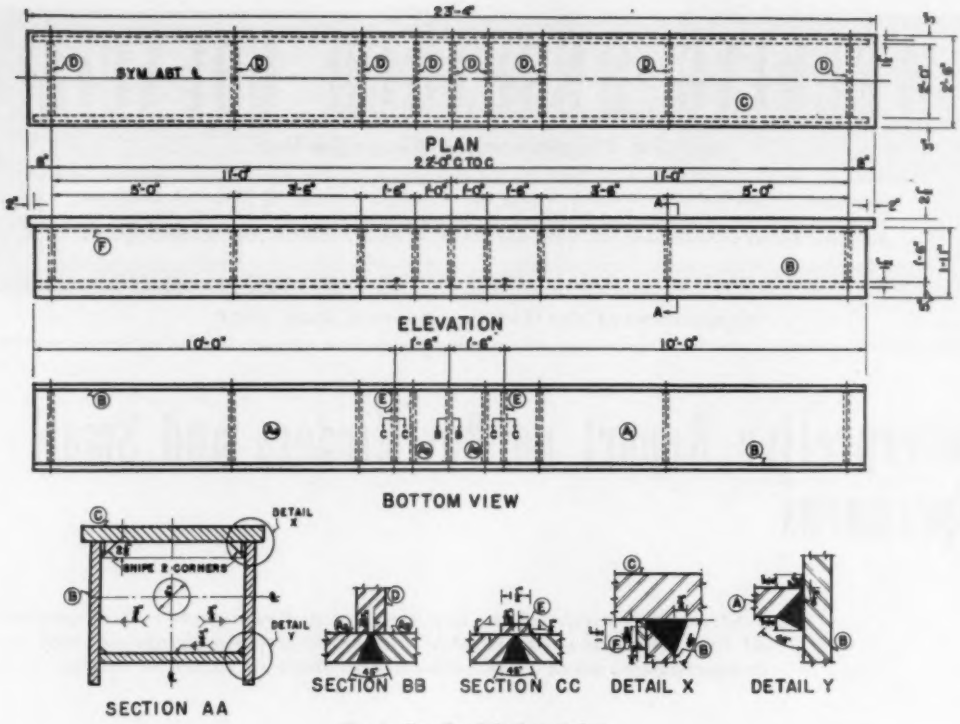


Fig. 1 Details of the box girders

because it simulates and exaggerates the condition which is suspected of having caused trouble in ships and other welded structures. In order to eliminate other factors, the effects of which might overshadow the factors being investigated and cloud the interpretation of results, it seemed to be important to eliminate serious defects of workmanship and incipient cracks prior to testing. Therefore, the welding was carried out under controlled procedure and with inspection, including magnetic particle examination. As time passed it became evident that this series of tests might offer opportunity to obtain transition temperature data. Transition temperatures in structures had been taking on an ever-increasing importance and this was added as an additional new objective of the series. To accompany this phase, a program of auxiliary tests was added.

DETAILS OF DESIGN

The details of design and the proportions of the box girder purposely did not conform to good design practice in certain respects. These details were arranged and chosen to produce an unusually large amount of constraint against ductile behavior and restraint against weld shrinkage. For example, the diaphragms are made of $1^1/_2$-in. thick material, considerably heavier than would normally be required; and the corners of the diaphragms have been extended into the tension-side corners of the box, whereas good design practice would require that they be sniped generously to avoid a complicated intersection in the corners, especially where such thick material is involved. Also, the sizes of welds, particularly the fillet welds and the "reinforcement" of the corner butt welds of the girder, were made considerably larger than necessary, to provide more constraint and, also, to introduce more shrinkage forces. A welding sequence was specified which was expected to create "reaction type" stresses. The same sequence of welding was used on each of the girders and great care was taken to eliminate defects of workmanship during the welding and any possible incipient cracks prior to testing.

All girders were fabricated by the Ingalls Shipbldg. Corp., Pascagoula, Miss. The first girder was made of semikilled steel. It was essentially the same as in Fig. 1, and run as a pilot test. The next four girders were of design identical to Fig. 1 and were from one heat of steel. The steel was a plain low-carbon, open-hearth steel conforming to the requirements of A.S.T.M. A-7 with special provisions requiring that it be fully killed. This steel had good notch toughness properties at temperatures near freezing. (See Fig. 4.)

RESULTS OF GIRDER TESTS

The girders were tested at a controlled temperature as

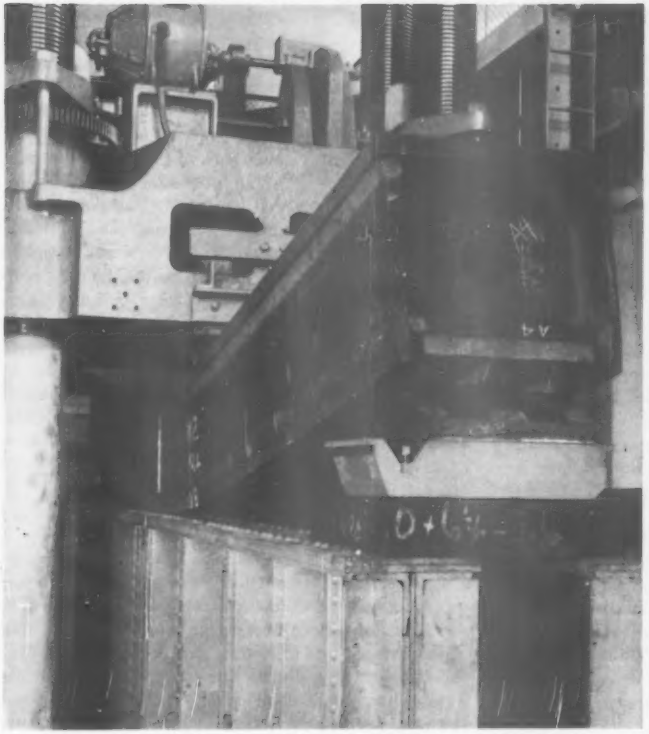


Fig. 2 Loading arrangement

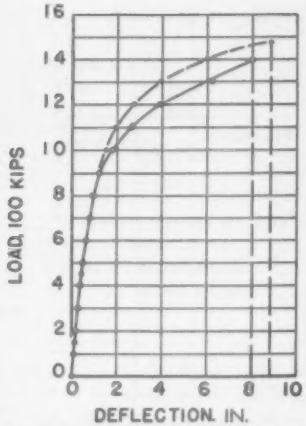


Fig. 3 Load-deflection curves for two box girders

Solid line, open circles, a girder of semikilled steel tested at 80° F. Dash line, solid circles, a girder of fully killed steel tested at 0° F.

simply supported beams in the laboratory of the Engineering Mechanics Section of the National Bureau of Standards. The girder of semikilled steel was tested at room temperature and broke with a square type fracture. One girder of fully killed steel was tested at each of the temperatures −40, 0, 40 and 80° F. The girders tested at −40° F. and at 0° F. broke with a square type of fracture; but even the girder tested at −40° F. withstood a 2.45-in. permanent deflection before fracture. The mechanical stress relieving thus involved would surely have ironed out virtually all the residual stresses in advance of fracture. The other two girders exceeded 16 in. deflection on a 22-ft. span without fracture. (See Fig. 2.)

The tests results of the four girders made of fully killed steel are summarized in Table 1.

Table 1—Summary of Flexural Tests of Four Identical Box Girders

Temperature, ° F.	*Maximum load, kips.*	*Maximum moment,* kip. in.*	*Modulus of rupture,* kips./in.²*	*Maximum deflection, in.*	*Specimen No.*
−40	1165†	59,400	63.1	2.45	BG 2
0	1476†	75,300	79.9	8.83	BG 3
+40	1670‡	85,200	90.4	16.16	BG 4
+80	1685‡	85,900	91.2	18.06	BG 5

* As computed from the load at failure or from the maximum load that was reached.
† Load at rupture.
‡ Maximum load that was reached. No rupture.

The load-deflection curve for the girder of fully killed steel that was tested at 0° F., and that for the one fabricated from semikilled steel and tested at room temperature are shown in Fig. 3. The results of the tests of these two girders are compared in Table 2. These results show that the girder of fully killed steel, even though tested at 0° F., was somewhat superior in load properties to the girder of semikilled steel at 80° F.

Table 2—Results of Flexural Tests of Two Box Girders

Girder	*Semikilled, BG 1*	*Fully killed, BG 3*
Temperature of test, ° F.	80	0
Maximum load, kips.	1397	1476
Maximum moment, in. kips.	71,200	75,300
Modulus of rupture, kips./in.²	75.6	79.9
Maximum deflection, in.	8.00	8.83
Energy to failure, kip. in.	8350	10,060

METALLURGICAL AND SMALL SPECIMEN STUDIES[2]

The primary objective of this phase of the box girder investigation as established originally was to attempt a prediction of the performance of the box girders from small-scale laboratory test specimens prepared from the girder material. This work was carried out by the Naval Research Laboratory. The only possible performance criterion for the box girder was the lowest temperature 40° F. at which the structure resisted fracture in bending to the limit of deflection. A variety of small-scale test specimens which had been used pre-

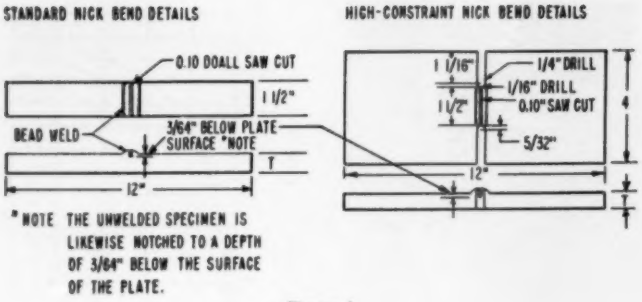


Figure 4

viously for performance evaluation were applied to these studies. These included: standard nick bend; high constraint nick bend test; and Charpy V specimens. In most cases the tests were performed on prime plate material as well as on bead-welded samples. Figure 4 gives details of the specimens, bead welds and notch locations.

The tests included not only specimens of the various plates of the girders, but, also, specimens of material from several positions in these plates and in the two directions, transverse and longitudinal, relative to rolling. The effect of welding was likewise evaluated on a sampling basis by bead welding a wide selection of the specimens described above.

Chemical Composition and Microstructure

The chemical composition of the steel used in constructing the girders was determined for each of the several plates comprising girders 1 and 2. Check analyses were also made on plates of girders 3 and 4. The results are presented in Table 3. No significant variations in chemical composition were noted between plates of a single girder or between the plates from different girders made of the fully killed steel.

Table 3—Chemical Analysis (Av. for Various Plates of Girders)

Girder	*C*	*Mn*	*Si*	*S*	*P*	*Al*	*N*
BG1 (semi-killed)	0.25	0.57	0.06	0.032	0.014	0.01	0.011
BG2-3-4 (killed)	0.21	0.57	0.21	0.029	0.017	0.027	0.006

Metallographic examination disclosed that all plates investigated had a coarse-grained, ferrite pearlite microstructure with the exception of one end of the $2^1/_2$-in. BG2 plate which showed a fine-grained, banded structure.

Radiographic Examination of Welds

Radiographic examination of some of the welded joints in the vicinity of midspan of girders 1 and 2 was made to ascertain the general quality of the welds. Forty-four locations in Girder 1 and 48 locations in Girder 2 were examined. The radiographs disclosed heavy porosity and slag inclusions in some of the groove welds, scattered slag inclusions in the diaphragm fillet welds of Girder 1 and semi-continuous slag inclusions in both groove welds and the fillet welds of Girder 2. In some cases the continuity of the defects indicated a lack of fusion. Thus, the radiographs disclosed notches in the form of weld defects which may be deemed to be present to a greater or lesser extent in any large welded structure. Regions of slag entrapment were exposed by the fracture in BG2. These defects may have contributed to the failure of BG2.

Small Specimen Tests

The performance of a complex welded structure represents the integrated effect of mechanical and material factors. Mechanical factors include the imposed conditions of service and design which determine the state of stress, rate of loading, temperature, etc. Material factors include the numerous, elusive elements which characterize steel quality such as notch and strain-rate sensitivity, strain-aging susceptibility, etc. The relative importance, or additivity, of these factors cannot be assessed directly. Accordingly, we are confronted with a perplexing individuality of performance which is shown by structures and specimens alike. There is no doubt that a basic extension of our knowledge background relative to flow and fracture of metals is required for an over-all solution to this problem. This fact is generally accepted; however, there remains now as well as at the time this investigation was begun the question of the feasibility of an empirical approach aimed at correlating quantitatively the performance of simple specimens with the performance of complex structures. Such an approach does not require an understanding of the mechanisms involved, it is predicated entirely on the comparisons of end results. Thus, the basic question which was asked for and provided by this correlation study was: Having the end results of the box-girder performance could some particular specimen taken from the same material as the structure be made to show the same end result in terms of transition temperature?

The various criteria and definitions of transition temperature generally used in the investigation of laboratory specimens were examined for a quantitative prediction of box-girder performance. Only the $1^1/_2$-in. material of the fully killed steel was examined in this connection because failure in the girders initiated in the $1^1/_2$-in. bottom or side plates.

A summary of transition temperature data is pre-

sented in Fig. 5. It is noted that performance is indicated to vary considerably depending upon the criteria and attending definitions of transition temperature and also with type, location and orientation of specimens.

Briefly, if an arbitrary choice is made of the many possibilities of correlation afforded by this collection of transition data the following may be deduced:

1. The standard nick bend specimen indicated correlation in the case of notch perpendicular to plate surface when energy after maximum load is used as transition criterion.
2. The Charpy V specimen indicated correlation on a basis of 15 ft.-lb. transition criterion.

Thus, the results of this investigation show that it is possible by arbitrary selection of specimen and transition criterion to find a transition correlation purely by virtue of the wide range of transition temperatures which are provided by the varied specimens and criteria. The illusory and fortuitous nature of such quantitative correlations is, however, clearly indicated.

It is first of all shown that the various specimens, procedures of testing and criterions of transition show specific and different sensitivities to changes in the material variables of the steels. Thus, a change in the steel used for the structure could be expected to change not only the performance of the structure, but, also, of the various specimens used for correlation and not uniformly in the same direction or to the same degree.

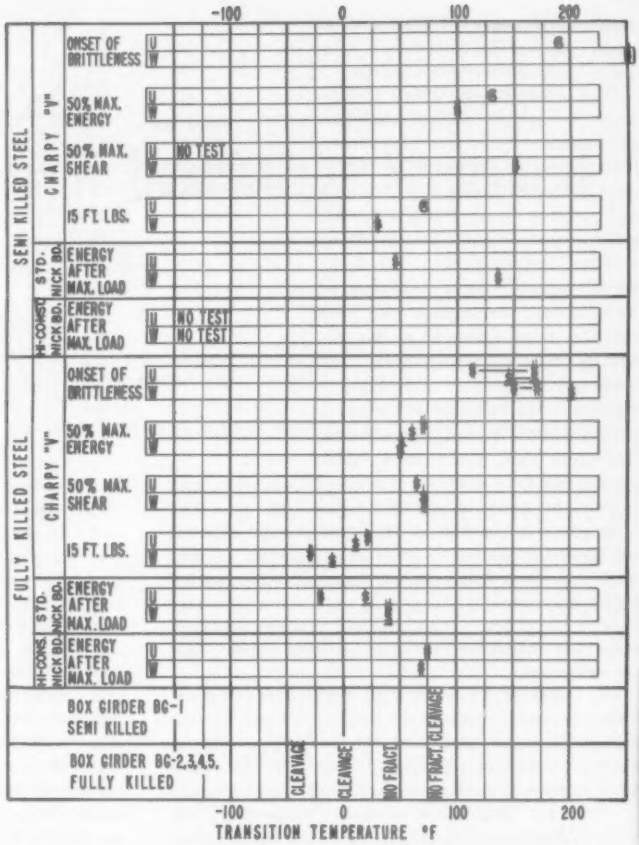


Fig. 5 Summary of transition temperature data on 1 1/2-in. plates, showing the extent to which heterogeneity, choice of test specimen and choice of performance criterion complicate correlation

This would hold true even if the steels were perfectly homogeneous and isotropic. Real materials, however, are neither homogeneous or isotropic. Evidence is presented of the extreme effects on the performance of single specimens occasioned by the location and orientation of the specimens within a single plate of one of the box girders. Thus, the position, direction, etc., of specimens which should be deemed significant for correlation presents a problem of "sampling" which is most difficult to resolve.

The effects of welding provide further complications. These effects have been shown to vary inexplicably depending on the orientation of notch, location of specimen and grain size. Some specimens show pronounced effects due to welding while others are completely unaffected.

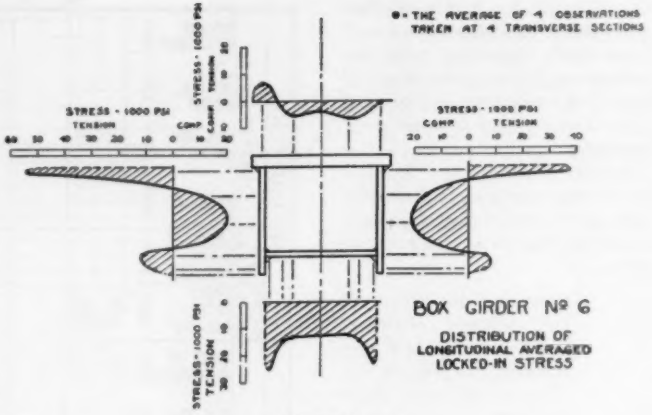
It should be emphasized that this combined evidence merely refutes the concept of a rigorous, quantitative correlation between simple specimens and structures and in no way indicates that significant information may not be drawn from the performance of such simple specimens.

MEASUREMENT OF RESIDUAL STRESSES[4]

A sixth girder made in identically the same way and with the same procedure was fabricated and then trepanned for the purpose of determining the distribution of the locked-in stresses. These stresses were obtained by the relaxation method, and changes in strain were

measured by means of SR-4 electrical strain gages. The girder was subdivided at four transverse sections.

Data obtained from these trepanning investigations showed that the axial stresses in the web plates vary from a residual tensile stress of the order of the yield point of the material at the upper corner welds, to a compressive stress of about 20,000 psi. at mid-height of the girder. The thick, top flange plate is the most irregular in its behavior; the stresses vary considerably from section to section, although in the main they retain their compressive character. Of particular interest is the behavior of the lower flanges and the bottom corner welds. The entire width of the bottom plating appears to be in a state of longitudinal tension, with a mean intensity of approximately 13,000 psi. The lower corner weld stresses are moderate, 22,000 to 28,000 psi. tension instead of the yield point intensity. These relatively low welding stresses may have been considerably influenced by the welding sequence used in fabricating the girder. It is significant that the top flange plate was welded last, making the upper corner welds the closing ones.


● = THE AVERAGE OF 4 OBSERVATIONS TAKEN AT 4 TRANSVERSE SECTIONS
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BOX GIRDER Nº 6
DISTRIBUTION OF LONGITUDINAL AVERAGED LOCKED-IN STRESS

Figure 6

The transverse locked-in stress distribution has somewhat the same pattern as the longitudinal stress at the web plates of the box girder. At the flanges, however, there are significant differences. The curves for transverse stresses here are approximately the mirror images of those for longitudinal stresses; moderately high transverse tension at the heavy top flange and very low transverse compression at the bottom flange. The bottom flange shows tension at the edges, changing to slight compression across the center. There was good agreement between points located symmetrically with respect to the vertical axis. See Fig. 6 for average longitudinal stresses. Within the limits of the experimental errors, and inherent limitations in the methods of analysis used, the data satisfy the equilibrium requirements of internal forces and resisting moments. The closing pass or weld may profoundly affect the stress distribution.

GENERAL CONCLUSIONS

The findings of this project substantiate other related evidence and justify the following general conclusions relating to welded structures.

1. Residual stresses of high magnitude in a complex highly restrained structural member of reasonably good structural steel material and of comparatively heavy proportion and internal constraint do not destroy the useful carrying capacity of the member under static loading even at low winter temperatures even though the structure contains moderate notch effects at critical points which unavoidably result from practical design and workmanship. "Residual stresses" as used broadly in the above statement includes both local residual stresses and the more general "reaction" stresses.

2. In the process of fabrication of this highly restrained structure it was demonstrated that the sequence of welding and welding procedure have an important effect on shrinkage stresses. If ignored they may cause a weld to crack during fabrication. If they are properly planned, such cracking can be avoided in steel materials of the kind involved in this project.

3. Semikilled steel in a structure provides substantially less carrying capacity and when tested to destruction would shift from ductile to "brittle" fracture at a higher temperature than a good fully killed steel. A restrained structure made of fully killed steel with proper design and workmanship, even though containing high residual stresses, can operate safely under static stresses at low winter temperatures if it contains only moderate notch effects, such as those mentioned under conclusion No. 1.

4. For rigid monolithic structures subjected to low winter temperatures it is desirable to use extra precautions in design, workmanship and selection of materials.

5. In our present state of knowledge small specimens cannot be relied upon to predict the behavior of welded structures. On the other hand, any of a variety of small specimens may be used to select superior steels and to assess the heat effects of the welding cycle on the stability of these steels for field-erected structures subjected to low winter temperatures.

6. Arbitrarily selected criteria and definitions give different transition temperatures. This complication is basic to the mechanics of test and not inherent in the structures nor in the materials.

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Spot Welding of Scaly Heavy-Gage Structural Steel

Satisfactory spot welding conditions for rust-free, scaly structural steel were established in the 3/16- and 3/8-in. gage, utilizing a high pressure-low current preheat and a low pressure-high current weld sequence

by Ernest F. Nippes and John N. Ramsey

SUMMARY

SATISFACTORY spot welding conditions for rust-free, scaly structural steel were established in the 3/16- and 3/8-in. gage, utilizing a high pressure-low current preheat and a low pressure-high current weld sequence. For the as-welded 3/8-in. gage material, the normal tension to shear strength ratio exceeded the minimum arbitrary limit of 45%. With the 3/16-in. gage, it was found necessary to temper the welds by the passage of additional current, after a proper cool time, while the metal was still between the jaws, if the normal tension to shear strength ratio was required to be greater than 35%.

It was found that electrode life was considerably lowered by the welding of scaly stock and that expulsion of metal was usually present to some degree, even at the recommended conditions. The coefficient of variation for weld strength was in the range of 5 to 10%, indicating only a fair degree of consistency. However, the strengths of welds made in the scaly stock compared quite favorably with the weld strengths of grit-blasted material.

INTRODUCTION

This program, approved and guided by the Resistance Welding Research Committee and by the Subcommittee for Spot Welding of Steels, was financially supported by the Welding Research Council of the Engineering Foundation. This investigation was a continuation of the program involving the spot welding of heavy-gage structural steel which has been carried out in this laboratory.

A preliminary study of the spot-welding of 3/8-in. scaly structural steel was carried out in this laboratory and was reported by Doty and Childs.[1] This was followed by a broader investigation of cleaned structural steel of 1/8-, 3/16-, 1/4-, 3/8- and 1/2-in. gages, reported by Nippes and Underhill.[2] In order to assure a minimum waste of time, money and effort, maximum use was made of this previous work.

The object of this investigation was to find the effects of the spot-welding variables, and to find the optimum spot-welding conditions for rust-free scaly structural steel of 3/16- and 3/8-in. gages. Since the everpresent thought was toward production methods, complex sequences of electrode force and current were avoided as far as possible.

MATERIAL

The chemical composition and tensile strength of the open-hearth mild structural steels, used in the "as hot-rolled" condition, are shown in Table 1.

Although the steel was stored indoors, rusting had taken place to some degree in small areas. As this investigation was to be of "scaly" structural steel, it was necessary to remove the rust, but not the mill scale. Therefore, all pieces of steel were hand wire-brushed to the extent that an operator would in a production shop.

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Table 1—Chemical Analysis and Tensile Strengths

Gage thickness, in.	*Strip width, in.*	*Carnegie-Ill. heat number*	*C, %*	*Mn, %*	*P, %*	*S, %*	*Tensile strength, psi.*
3/16	2	04 K061	0.22	0.47	0.008	0.032	64,560
3/8	3	29 D181	0.24	0.45	0.015	0.033	62,900

EQUIPMENT

All welding was done on a 175-kva., press-type, motor-driven, air-cushioned resistance welder. The timing and current control was achieved by means of commercially available standard welding controls. A current regulator was used to compensate for changes in line voltage, and changes in secondary impedance due to different shaped specimens and different contact resistances of the scale. Welding current was measured by means of a recording ammeter connected to a current transformer in the primary circuit of the welding transformer. The timing measurements were made by twin synchronous clocks which alternated as successive stages of the complete welding cycle occurred. All strength tests and measurements were made on a Baldwin-Southwark universal testing machine.

The welding electrodes, classified according to R.W.-M.A. as Group A, Class 2, were cooled by circulated water maintained at 40–45° F.

GENERAL PROCEDURE

Electrode size, shape and forces were chosen the same as for the clean steel as determined in the previous investigation.[2] Since preheating was found necessary to avoid excessive expulsion with scaly stock, preheat currents and times were established for the two gages, and were maintained throughout the investigation. A high pressure-low current scheme was used during preheating to break down the mill scale. A lower pressure-higher current arrangement was used during welding, with a high forge pressure applied about 10 cycles before the end of the welding time. This forge pressure was of the same magnitude as the preheat pressure, and was maintained through any cool time and tempering time in order to keep as simple a pressure sequence as possible, to conform to limitations of standard production spot welding controls. Some welds were tempered while still between the electrodes by passing a current through the weld after the weld and heat-affected zone had been allowed to cool below the M_f temperature of the steel.

To find the variation of weld diameter with welding current and time, welds were sectioned as near as possible to the center line of the electrode indentation, polished, and macroetched to show the fused zone, or nugget. Since quite a variation was noticed in the diameters thus measured, a statistical study of 100 welds was made for various welding currents and times. Approximate values of welding currents and times were thus chosen which would be expected to give optimum strengths. Normal tension and shear tests samples were then welded and tested according to the *R.W.M.A. Handbook*.[3] The ratio of the normal tension strength to the shear strength, a measure of ductility, was used as one criterion of acceptability. It was found, with the $^3/_{16}$-in. gage, that weld times up to 6 sec. did not improve the normal tension to shear ratio to the arbitrary minimum of 45% used in the previous reports. A possible explanation for this behavior would be based on the greater cooling effect of the electrodes when used on thinner material. Since the normal tension to shear ratio for as-welded, $^3/_{16}$-in. gage steel did not exceed the arbitrary value of 45%, the variation of this ratio with cool time and temper current was studied for this material.

DISCUSSION OF RESULTS

Preheating the Scale

As defined previously in this laboratory by Doty and Childs,[1] the maximum current producing a minimum of expulsion was called the preheat current, and the time, at this current, just necessary to produce fusion was called the preheat time. The lack of consistency in the thickness and quality of the mill scale, which was the main difficulty throughout this investigation, made the determination of the preheat current difficult. There was some surface expulsion, between electrodes and

Table 2—Average Weld Diameters for As-Welded $^3/_8$-In. Scaly Steel

Weld time, sec.	*Type of specimen*	*No. of specimens*	*Welding current, amp.*	*Weld diameter, in.*	*Weld diameter, average of N. T. and shear*	*Coefficient of variation of weld diameter, %*
4	Diameter	11	20,960	0.76		5.3
	N. T.	4	21,040	0.84	0.83	0.0
	Shear	6	21,080	0.81		5.0
4	Diameter	13	22,040	0.78		6.4
	N. T.	5	22,010	0.84	0.84	3.6
	Shear	6	22,000	0.84		4.8
4	Diameter	12	22,930	0.82		11.0
	N. T.	4	22,980	0.92	0.86	0.1
	Shear	4	22,980	0.80		5.0
4	Diameter	12	24,000	0.85		11.7
	N. T.	6	23,970	0.93	0.90	3.2
	Shear	4	23,980	0.87		2.3
4.5	Diameter	22	21,080	0.75		5.3
	N. T.	6	21,020	0.86	0.87	3.5
	Shear	4	21,030	0.88		2.3
4.5	Diameter	17	22,030	0.87		3.5
	N. T.	4	22,040	0.86	0.89	3.5
	Shear	7	22,030	0.91		4.4
4.5	Diameter	13	23,000	0.91		6.6
	N. T.	7	23,060	0.92	0.88	3.3
	Shear	4	23,020	0.84		3.6

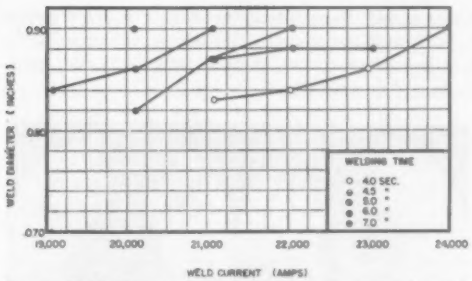

Fig. 1 Weld diameter as measured from strength specimens as a function of welding current for as-welded $^3/_{32}$-in. scaly steel

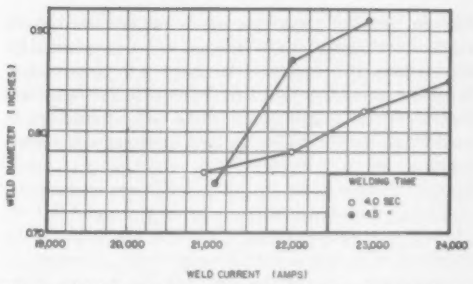

Fig. 2 Weld diameter as measured by sectioning as a function of welding current for as-welded $^3/_{32}$-in. scaly steel

sheets, with almost every preheat current investigated. It was necessary to compromise between higher currents, giving lower electrode life but shorter welding times, and lower currents, giving better electrode life but longer welding times. The values of preheat current and time which were chosen are listed in the table of optimum welding conditions, Table 6.

Weld Diameter

Great care was taken to have the final polished and etched surface through the center of the indentation of the electrodes, the only external measure of the center of the weld. However, since at the same welding conditions, there was considerable variation of weld diameter from weld to weld, it was decided to run a consistency study. During this consistency study, it was noticed that the weld nuggets on the etched surfaces sometimes were not symmetrical and were not always directly between the indentations of the electrodes, probably due to irregularities of the scale. Irregularly shaped weld nuggets were also found when normal tension specimens and shear specimens were tested, as shown later in Figs. 14, 15 and 16. These irregularities must have caused the large variations in weld diameters for welds made under identical conditions in various type specimens, as shown in Table 2. In determining the diameter of the fusion zone in a strength specimen, it was possible to take the average of several measurements of the fusion zone, whereas only one measurement could be made on a sectioned specimen. It may be seen in Table 2, that the diameters obtained by sectioning are in almost every case smaller than the diameters determined from strength specimens. This would seem to indicate at first thought, that the centers of the welds were not obtained by the sectioning, for any deviation from the center of a circular weld would give a smaller observed nugget. However, by a simple trigonometric calculation, it may be seen that only a very small decrease in measured weld diameter results from a fairly wide error in center location. For example, for a 0.88 in. weld diameter, nominal for $^3/_8$-in. gage, an error of $^1/_{16}$ in. in sectioning causes an apparent weld diameter of 0.87 in., and an error of $^3/_{32}$ in. causes an apparent weld diameter of 0.86 in., and for a 0.58 in. weld diameter, nominal for $^3/_{16}$-in. gage, the same errors in sectioning result in 0.57 in. and 0.56 in. diameters, respectively. Since it is felt that it was possible to section consistently to within $^1/_{16}$ in. of the center of the electrode indentation, the maximum decrease accountable to this experimental error is only 0.01 in. As shown previously in Table 2, the diameters by sectioning are from 0.02 to

Table 3—Average Mechanical Properties for As-Welded $^3/_{16}$-In. Scaly Steel

Weld time, sec.	*Type and No.*	*Welding current, amp.*	*—Weld strength— Lb.*	*Coeff. of variation*	*—Weld diameter— In.*	*Coeff. of variation*	*Indent, %*	*Sheet sep., %*	*Failure type*	*N. T./shear, %*
2	N. T. (4)	14,020	3,540	4.0	0.54	3.7	1.3	1.9	Shear	30.2
	Shear (4)	14,000	11,740	2.2	0.54	1.8	1.5	1.8	Shear	
2	N. T. (5)	15,030	3,810	2.1	0.56	3.6	1.4	1.6	Partial*	32.5
	Shear (4)	14,900	11,730	6.6	0.59	3.4	2.1	1.7	Partial	
2	N. T. (6)	15,490	3,780	4.0	0.58	3.5	1.0	3.6	Partial	31.7
	Shear (5)	15,490	11,910	7.5	0.56	3.6	1.3	3.6	Plug	
2	N. T. (5)	16,000	3,780	0.6	0.60	1.7	2.2	1.9	Partial	31.1
	Shear (6)	15,970	12,140	4.3	0.59	1.7	3.0	4.0	Partial	
2	N. T. (6)	16,940	3,960	1.3	0.61	3.3	3.1	3.0	Partial	35.5
	Shear (6)	17,060	12,460	5.3	0.62	4.8	2.1	3.1	Plug	
3	N. T. (4)	14,060	3,600	1.9	0.56	1.8	1.1	1.1	Partial	32.3
	Shear (4)	14,060	11,130	1.6	0.57	1.8	2.1	2.1	Plug	
3	N. T. (5)	14,960	3,870	0.5	0.59	1.7	1.5	2.7	Partial	35.8
	Shear (5)	14,940	10,850	2.3	0.59	1.7	2.7	2.2	Partial	
3	N. T. (4)	16,030	3,940	2.3	0.63	1.6	0.7	2.4	Partial	32.5
	Shear (5)	16,000	12,110	8.9	0.63	3.2	3.0	4.0	Partial	
3	N. T. (6)	16,990	4,050	5.0	0.64	1.6	3.2	3.8	Partial	33.6
	Shear (5)	17,020	12,050	5.3	0.68	5.9	2.7	5.0	Plug	

* Partial plug.

0.09 in. smaller than the diameters obtained from strength test specimens, which can only be explained by the irregular and asymmetrical shape of the fusion zone. A further indication that this decrease is due to irregularities of weld nugget shape is the larger variations in weld diameters by sectioning than by strength test specimens as shown in Table 2 by the coefficients of variation of the weld diameter. The coefficient of variation of a set of values, calculated according to the *A.S.T.M. Manual on the Presentation of Data*,[4] is the ratio of their standard deviation to their average value, expressed as a percentage. As may be seen in Table 2, some of the values of this coefficient are quite large, an indication of poor consistency.

An interesting example of the need of many samples when working with inconsistent values may be seen in Table 2. The weld diameters found from normal tension specimens are incompatible, as are the weld diameters from shear test specimens. Yet, when the weld diameters found by normal tension are averaged with those by shear tests, the total number of samples is increased, and the resulting curves in Fig. 1 are rather smooth and consistent. The corresponding weld diameter-current curves, derived from sectioned specimens, are shown in Fig. 2.

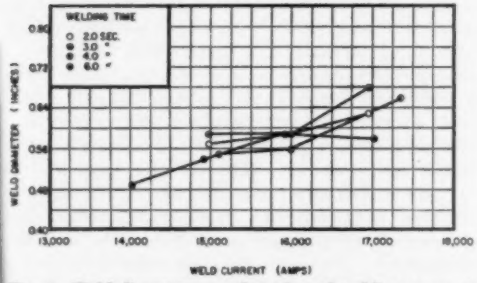

Fig. 3 Weld diameter as a function of welding current, preliminary investigation on $^3/_{16}$-in. scaly steel

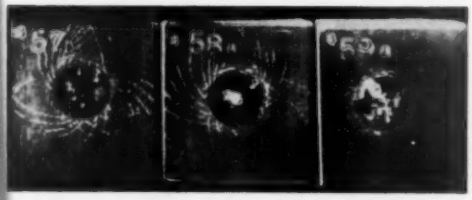

Fig. 4 The 1st, 2nd and 3rd welds with newly machined electrodes on $^3/_{16}$-in. scaly steel

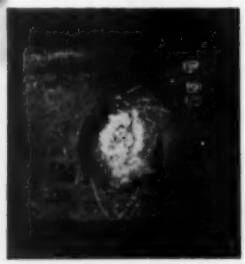

Fig. 5 A 25th weld on $^3/_{16}$-in. gage scaly steel, showing excessive pickup of the electrode copper by the steel

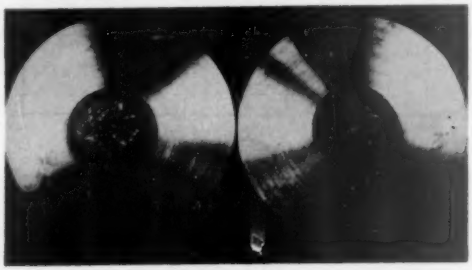

Fig. 6 Electrodes after 15 welds on $^3/_{16}$-in. scaly steel at optimum conditions

Fig. 7 Electrodes after 48 welds on $^3/_{16}$-in. scaly steel at optimum conditions

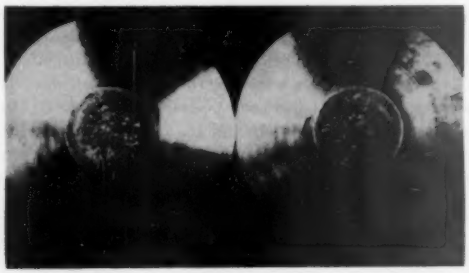

Fig. 8 Electrodes after 76 welds on $^3/_{16}$-in. scaly steel at optimum conditions

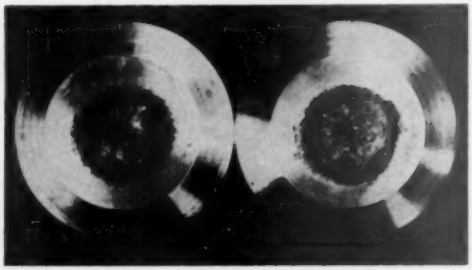

Fig. 9 An unlimited diameter electrode after 32 welds on $^3/_{16}$-in. scaly steel at near optimum welding conditions

The original plan was to use the same weld diameter as had been obtained previously with clean structural steel of the same gages.[2] As shown in Figs. 1 and 2, it was possible to obtain the nominal 0.88 in. weld diameter with the $^3/_8$-in. gage. In an attempt to attain the nominal weld diameter for $^3/_{16}$-in. steel, 0.71 in., the welding current was increased as high as possible (17,000 amp.) before expulsion became too severe, and welding times were increased to as long as 6 sec. Although the weld diameters increased a small amount, the value of 0.71 in. was not attained, as shown in Fig. 3. Unlimited diameter, spherical-tipped electrodes were tried over the same range of currents and times, but the results were similar to those found with domed electrodes of restricted diameter. As a result of the above tests, a nominal weld diameter of 0.58 in. was selected for the scaly $^3/_{16}$-in. material, using restricted diameter electrodes.

Electrode Deterioration

A great detriment to the spot welding of scaly steel on a production basis is the deterioration of the original contour of the electrodes. The electrode surface starts to be consumed and pitted with the first weld, and each succeeding weld does further damage. Figure 4 shows the first, second and third welds, reading from left to right, made with new electrodes at currents somewhat less than the nominal welding current of 15,500 amp. for $^3/_{16}$-in. gage steel. The pickup of the copper of the electrode by the steel may be seen in this figure as well as in Fig. 5, in which a case of excessive pickup is shown, where the surface globule of copper was approximately 0.025 in. thick. This was obtained on the 25th weld at 15,000, 16,000 and 17,000 amp. with unlimited diameter ten-inch radius domed electrodes.

The progressive deterioration of the surface contour of the electrodes is shown in Figs. 6 through 9. Figures 6, 7 and 8 show the changes in the electrode surface after 15, 48 and 76 welds, respectively, at optimum welding conditions for $^3/_{16}$-in. gage, 15,500 amp. for 2 sec. Figure 9 shows the electrode surface of an unlimited diameter electrode after 32 welds at approximately 16,000 amp. An interesting indication of the loss of surface contour was noticed in an appreciable decrease in weld diameter when newly machined unlimited diameter electrodes were substituted after 32 welds. In this case, the weld diameter with a welding current of 16,000 amp. for 2 sec. was 0.63 in. with old electrodes, and 0.53 in. with freshly machined electrodes, and with 16,000 amp. for 3 sec. the weld diameter was 0.65 in. with old electrodes and 0.59 in. with n · electrodes. Thus, the effective electrode diameter was increased appreciably by the 32 welds, as shown by increased weld diameters. Using restricted diameter electrodes, as recommended in this report, this effect was much less pronounced. Generally speaking, it was found necessary to redress the electrodes after approximately 200 welds had been made at recommended conditions.

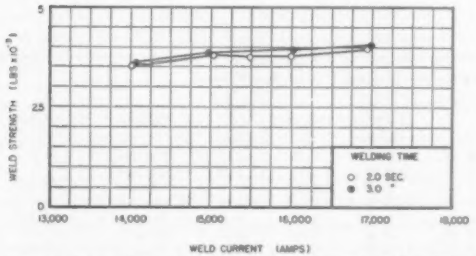

Fig. 10 Normal tension strength as a function of welding current for as-welded $^3/_{16}$-in. scaly steel

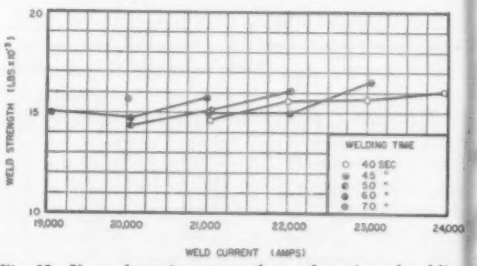

Fig. 12 Normal tension strength as a function of welding current for as-welded $^3/_{16}$-in. scaly steel

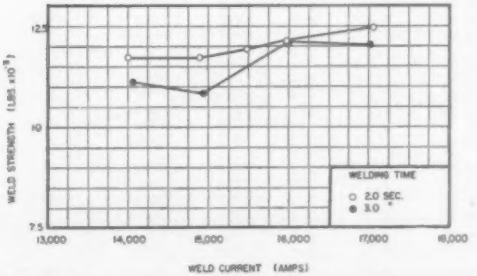

Fig. 11 Shear strength as a function of welding current for as-welded $^3/_{16}$-in. scaly steel

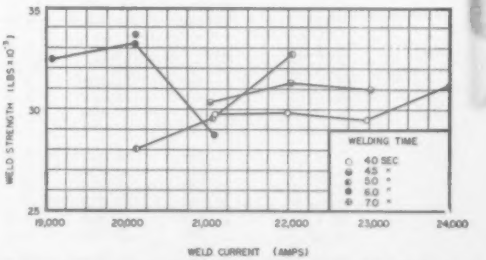

Fig. 13 Shear strength as a function of welding current for as-welded $^3/_{16}$-in. scaly steel

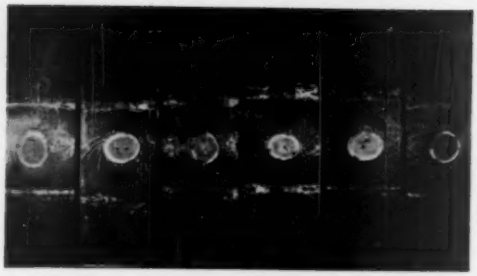

Fig. 14 $^3/_{16}$-in. gage normal tension specimens after having been tested

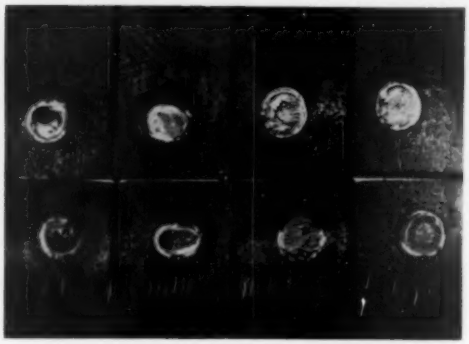

Fig. 15 $^3/_8$-in. gage shear specimens after having been tested

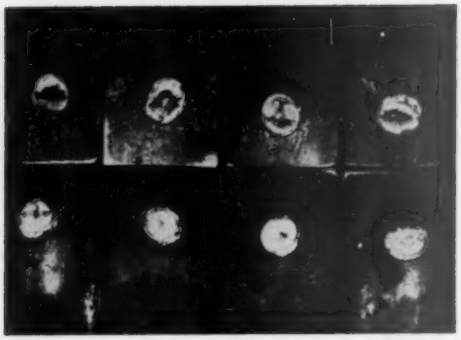

Fig. 16 $^3/_8$-in. gage shear specimens after having been tested

Expulsion

The initial expulsion which occurred during preheating was usually of small intensity and originated predominantly from the electrode to steel interface. The expelled particles, moving in a magnetic field, traveled in curved paths, as may be seen by the tracks in the mill scale in Figs. 4, 5, 14, 15 and 16. During welding, the expulsion was predominantly from the steel-to-steel interface and varied considerably in intensity from specimen to specimen. In some cases expulsion was slight, consisting of one or two small particles, in some cases, heavy, consisting of four or five large glowing globules of steel traveling 10 to 15 ft. horizontally outward from the machine, and in some cases expulsion was excessive,

Table 4—Average Mechanical Properties for As-Welded $^3/_8$-In. Scaly Steel

Weld time, sec.	*Type and No.*	*Welding current, amp.*	*—Weld strength—* *Lb.*	*Coeff. of variation*	*—Weld diameter—* *In.*	*Coeff. of variation*	*Indent, %*	*Sheet sep., %*	*Failure type*	*N. T./shear, %*
4	N. T. (4)	21,040	14,710	6.5	0.84	0.0	2.6	2.7	Partial	49.5
	Shear (6)	21,080	29,780	7.1	0.81	5.0	2.6	1.9	Partial	
4	N. T. (5)	22,010	15,680	5.7	0.84	3.6	1.8	2.9	Partial	52.5
	Shear (6)	22,000	29,830	8.2	0.84	4.8	2.4	1.8	Shear	
4	N. T. (4)	22,980	15,750	2.5	0.92	1.1	2.2	3.6	Plug	53.4
	Shear (4)	22,980	29,500	2.9	0.80	5.0	2.0	2.3	Shear	
4	N. T. (6)	23,970	16,190	5.2	0.93	3.2	2.6	3.9	Plug	51.9
	Shear (4)	23,980	31,200	4.9	0.87	2.3	0.9	3.6	Shear	
4.5	N. T. (6)	21,020	15,080	2.6	0.86	3.5	1.8	3.2	Plug	49.7
	Shear (4)	21,030	30,350	9.5	0.88	2.3	3.4	2.2	Shear	
4.5	N. T. (4)	22,040	14,780	3.7	0.86	3.5	2.0	2.1	Plug	47.1
	Shear (7)	22,030	31,370	9.6	0.91	4.4	2.5	2.3	Shear	
4.5	N. T. (7)	23,060	16,690	15.2	0.92	3.3	2.2	2.7	Plug	53.8
	Shear (4)	23,020	31,000	9.8	0.84	3.6	1.5	2.7	Shear	
5	N. T. (4)	20,050	14,440	3.5	0.83	1.2	2.4	2.4	Plug	51.4
	Shear (7)	20,110	28,090	11.0	0.81	2.5	1.5	2.1	Shear	
5	N. T. (3)	21,040	15,200	3.3	0.86	5.8	2.6	2.8	Plug	51.4
	Shear (7)	21,060	29,570	5.0	0.88	5.7	3.4	2.3	Shear	
5	N. T. (3)	22,040	16,170	1.8	0.93	3.2	3.0	3.0	Plug	49.4
	Shear (5)	22,040	32,740	5.5	0.86	3.5	2.3	2.5	Shear	
6	N. T. (7)	19,060	15,030	2.9	0.83	1.2	2.5	2.9	Plug	46.4
	Shear (5)	19,070	32,420	6.3	0.85	1.2	1.0	2.8	Shear	
6	N. T. (3)	20,060	14,860	2.1	0.86	0.0	2.6	2.7	Plug	44.7
	Shear (3)	20,100	33,230	3.5	0.86	2.3	2.4	3.3	Shear	
6	N. T. (3)	20,990	15,850	2.9	0.91	2.2	2.8	3.4	Plug	55.1
	Shear (4)	21,090	28,730	1.6	0.89	2.2	2.4	2.2	Shear	
7	N. T. (3)	20,020	15,750	0.9	0.90	2.2	2.9	3.6	Plug	46.7
	Shear (5)	20,110	33,640	3.5	0.89	4.5	2.0	2.7	Shear	

Table 5—Average Mechanical Properties for Welded and Tempered $^3/_{16}$-In. Scaly Steel

Cool time, sec.	Type and No.	Temper current—Weld current, %	Temper current—Amp.	Weld strength—Lb.	Weld strength—Coeff. of variation	Weld diameter—In.	Weld diameter—Coeff. of variation	Indent, %	Sheet sep., %	Failure type	N. T./-shear, %
	N. T. (6)	0	...	3,780	4.0	0.58	3.5	1.0	3.6	Partial	31.7
	Shear (5)	0	...	11,910	7.5	0.56	3.6	1.3	3.6	Plug	
4	N. T. (5)	84.7	13,120	5,840	8.4	0.58	1.7	1.3	1.0	Plug	40.9
	Shear (5)	84.7	13,120	14,280	6.6	0.59	3.4	2.9	1.8	Shear	
4	N. T. (5)	89.9	13,930	6,210	4.5	0.59	5.1	2.2	1.7	Plug	45.2
	Shear (4)	89.3	13,840	13,710	6.9	0.57	1.8	2.4	2.8	Shear	
4	N. T. (6)	95.0	14,720	6,880	9.4	0.55	3.6	1.5	1.4	Plug	47.3
	Shear (4)	94.7	14,660	14,550	4.6	0.59	1.7	1.7	2.3	Shear	
4	N. T. (5)	100.7	15,600	7,180	4.5	0.56	5.4	2.4	1.6	Plug	47.7
	Shear (5)	100.7	15,600	15,030	8.8	0.58	1.7	1.8	2.4	Shear	
4	N. T. (4)	108.1	16,770	6,950	5.8	0.58	5.2	1.6	2.9	Plug	47.3
	Shear (4)	108.3	16,800	14,690	6.3	0.59	1.7	1.6	4.2	Plug	
	N. T. (6)	0	...	3,780	4.0	0.58	3.5	1.0	3.6	Partial	31.7
	Shear (5)	0	...	11,910	7.5	0.56	3.6	1.3	3.6	Plug	
5	N. T. (5)	84.4	13,090	5,080	5.3	0.57	1.8	2.4	1.3	Partial	36.2
	Shear (4)	84.9	13,140	14,050	4.2	0.58	1.7	2.7	2.5	Partial	
5	N. T. (4)	89.9	13,930	5,850	5.0	0.59	3.4	2.1	1.1	Plug	40.5
	Shear (4)	89.4	13,820	14,430	6.1	0.58	1.7	2.4	2.2	Shear	
5	N. T. (5)	94.7	14,660	6,260	8.6	0.57	1.8	2.1	1.4	Plug	43.4
	Shear (5)	94.4	14,630	14,440	4.1	0.57	1.8	2.2	2.3	Shear	
5	N. T. (5)	100.4	15,560	7,340	4.9	0.56	3.6	2.3	1.6	Plug	51.4
	Shear (5)	100.0	15,500	14,290	2.6	0.57	1.8	1.8	1.9	Shear	
5	N. T. (4)	108.7	16,830	7,760	8.8	0.57	3.5	1.5	3.5	Plug	54.7
	Shear (4)	108.7	16,830	14,180	6.8	0.59	1.7	1.6	3.9	Shear	
5	N. T. (4)	119.8	18,560	5,460	10.4	0.59	1.7	1.9	4.4	Plug	42.4
	Shear (4)	119.8	18,560	12,880	9.1	0.55	3.7	2.0	5.4	Plug	

where material seemed to flash from the whole side of the machine and travel 25 to 30 ft. Such excessive expulsion was experienced occasionally for almost all conditions of current and time, even with those chosen as nominal values. There was no method found for predicting which pieces of steel would so expel. There was no apparent correlation between previous rust spots and this heavy expulsion. However, as would be expected, the expulsion became more severe as the power input was increased. These glowing globules of steel inflict small, though fairly deep, skin burns, and therefore operators and any passersby must be protected.

Strength-Current Characteristics

After a preliminary study was made of the effects of welding current and time on weld diameter, normal tension and shear strength specimens were made and tested according to the *R.W.M.A. Handbook*.[3] The results of these tests for the $^3/_{16}$-in. gage are given in Table 3, and Figs. 10 and 11; while the results for the $^3/_8$-in. gage are shown in Table 4 and Figs. 12 and 13. Nominal values of current and time were selected, so that the normal tension and shear strengths of welds would not be appreciably changed by small variations in current and time during production. An additional factor, which was considered in selecting nominal values of welding current and time was the minimization of expulsion. As a result of these considerations, the following welding conditions were selected for the $^3/_{16}$-in. gage, 2 sec. welding time at 15,500 amp., and for the $^3/_8$-in. gage, 4.5 sec. welding time at 22,000 amp. A variation of $\pm 5\%$ from these specified welding currents would be considered a satisfactory range for welding these materials. Within this welding current range, the coefficient of variation of normal strength and shear strength was usually between the values of 5 to 10%.

Figures 14 to 16 show several normal tension and shear specimens after having been tested. There are several fusion zones illustrated in which there are round dark spots which appeared to be inclusions of mill scale which had melted and then solidified as spherical particles. Spectrographs were made of the original mill scale, the ground spherical particles and the steel to get

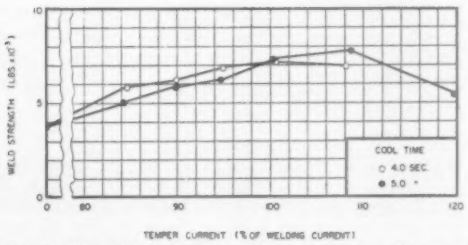

Fig. 17 Normal tension strength as a function of temper current for $^3/_{16}$-in. gage scaly steel, for two cool times

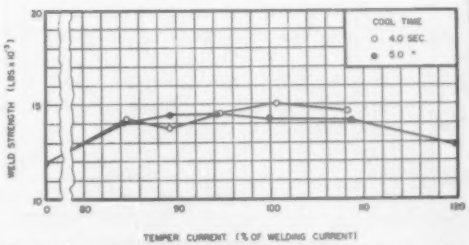

Fig. 18 Shear strength as a function of temper current for $^3/_{16}$-in. gage scaly steel, for two cool times

an iron pattern for a standard. Although the density of the iron lines in the spectrographs was greater for the mill scale than for the spherical particles for equal sample size and exposure, this cursory analysis indicated that the inclusions were composed of mill scale. There was insufficient time for a complete spectrographic analysis.

All welds made in this investigation had sheet separation and electrode indentation percentages less than the arbitrary maximum limits of 10 and 5% respectively, as measured and specified in the previous report.[2]

A measure of the impact strength of spot welds has been found to be the ratio of the normal tension strength to the shear strength of a weld. If this normal tension to shear ratio exceeds 45%, the welding conditions may be considered satisfactory from the toughness standpoint. Table 3 shows that normal tension to the shear ratio of as-welded, 3/16-in. gage steel never reached this arbitrary value of 45%. Although not shown in Table 3, this ratio did not reach the value of 45% even with welding times up to 6 sec. Thus, it was found necessary to temper the weld by passing an additional current through it, if normal tension to shear ratios greater than 35% were desired.

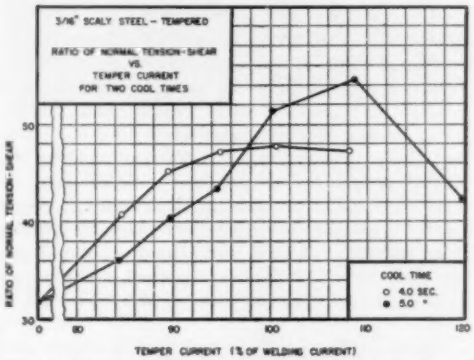

Fig. 19 Normal tension to shear strength as a function of temper current for 3/16-in. gage scaly steel, for two cool times

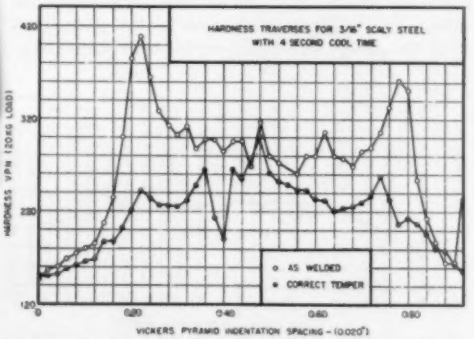

Fig. 20 Vickers hardness traverses for tempered 3/16-in. scaly steel with 4-sec. cool time

Table 6—Optimum Welding Conditions

Gage, in.	2/16	3/8
Welding electrodes		
Tip diameter, in.	0.80	0.937
Dome radius, in.	10	10
Taper, °	30	30
Preheat force, lb.	10,000	13,100
Welding force, lb.	6,000	6,100
Forge force, lb.	9,700	12,700
Preheat current, amp. (maximum)	9,600	14,700
Welding current, amp.*	15,500	22,000
Temper current % of welding current	95–110	...
Preheat time, sec.	1.0	4.5
Welding time, sec.	2.0	4.5
Cool time, sec.	4.0	...
Temper time, sec.	2.0	...
Weld diameter, in.	0.58	0.88
Normal tension strength, lb.	7,000	15,520
Shear strength, lb.	14,760	30,910
Ratio of N. T./shear, %	47.4	50.3

* Welding current variation should be held to ±5%.

Tempering

Tempering of the welds in the 3/16-in. gage was accomplished by passing an additional current through the weld while still between the electrodes after a proper cool time. Figures 17 and 18 show the normal tension and shear strengths for two cool times, as a function of the temper current, shown as a percentage of the welding current of 15,500 amp. The increase of the normal tension to shear strength ratio over that of the as-welded condition is shown in Fig. 19. A 4-sec., rather than a 5-sec. cool time, was chosen because the normal tension to shear ratio exceeded 45%, a shorter machine cycle was achieved, less variation in strengths and normal tension to shear ratio would be obtained by small variations in temper current, and a less complicated current cycle could be used since the temper current could be made equal to the welding current (95–110%). As an indication of the consistency of results, the coefficients of variation for the mechanical properties were in the range of 5 to 10% for these welding conditions.

This selection of cool time and temper current was verified by Vickers hardness surveys made across transverse sections at the center line of the electrode indentation. Figure 20 shows the surveys for the as-welded condition and the optimum-tempered condition for a 4-sec. cool time and Fig. 21 shows the as-welded, optimum tempered, and over-tempered conditions with a 5-sec. cool time. The rehardening of the over-tempered specimen, shown in Fig. 21, and in Fig. 22, a photomacrograph at 3.5 X, resulted from a temper current which reheated the steel into the austenitic condition. This rehardening accounts for the decrease in the normal tension to shear ratio curve for 5 sec. cool time shown previously in Fig. 19.

Optimum Welding Conditions

The optimum welding conditions, as determined in this investigation, are listed in Table 6. For the purpose of comparison, these welding conditions are listed again in Table 7, along with corresponding welding

Table 7—Comparison of Welding Conditions in Grit-Blasted and Scaly Material

Gage, in.	3/16	3/16	3/16	3/8	3/8
Surface condition	Grit-blasted	Grit-blasted	Scaly	Grit-blasted	Scaly
Welding electrodes					
Tip diameter, in.	0.687	0.80	0.80	0.937	0.937
Dome radius, in.	10	10	10	10	10
Taper, °	30	30	30	30	30
Preheat force, lb.	...	...	10,000	...	13,100
Welding force, lb.	6,000	6,000	6,000	6,500	6,100
Forge force, lb.	9,700	9,700	9,700	12,700	12,700
Preheat current, amp.	...	...	9,600	...	14,700
Welding current, amp.	29,400	32,000	15,500	26,000	22,000
Temper current % of welding current	84–87	91–95	95–110	...	...
Preheat time, sec.	...	...	1	...	4.5
Welding time, sec.	1	1	2	6	4.5
Cool time, sec.	4	4	4	...	...
Temper time, sec.	2	2	2	...	...
Weld diameter, in.	0.63	0.71	0.58	0.88	0.88
Normal tension strength, lb.	7,500	9,500	7,000	15,700	15,520
Shear strength, lb.	18,000	19,100	14,760	33,780	30,910
Ratio of N. T./shear, %	41.7	49.7	47.4	46.5	50.3

conditions previously determined in this laboratory for the grit-blasted material.[2] For the 3/8-in. gage, in which case it was possible to obtain the same weld diameter for both surface conditions, normal tension and shear strengths compare quite favorably. With the 3/16-in. scaly material, as explained previously, it was not possible to obtain the nominal 0.71 in. weld diameter, selected for grit-blasted material. Data for a 0.63 in., as well as a 0.71 in., weld diameter in grit-blasted stock have been included in Table 7. Considering the difference in weld diameters, 0.58 in. vs. 0.63 in., the mechanical properties of the welds in the scaly material are rather good. However, the comparison of strengths is less favorable when made between a 0.71-in. diameter weld in grit-blasted stock and a 0.58-in. diameter weld in scaly stock. In this case, a 25% reduction in strength is evidenced, resulting mainly from the smaller weld diameter.

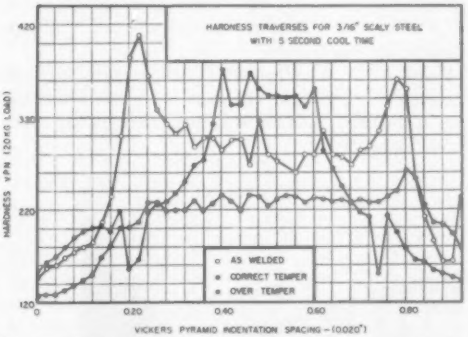

Fig. 21 Vickers hardness traverses for tempered 3/16-in. scaly steel with 5-sec. cool time

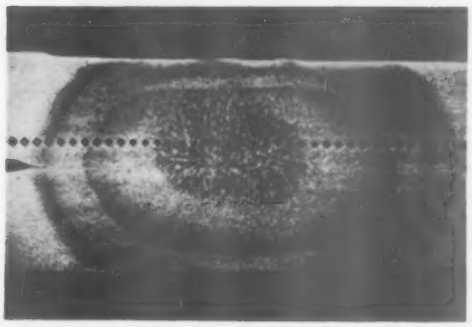

Fig. 22 Photomacrograph of section of welded and overtempered 3/16-in. gage steel, showing Vickers hardness traverse 3.5 ×

CONCLUSIONS

1. Satisfactory spot welding conditions for rust-free, scaly structural steel were established in the 3/16- and 3/8-in. gage, utilizing a high pressure-low current preheat and a low-pressure high current weld sequence.

2. For the as-welded 3/8-in. gage material, the normal tension to shear strength ratio exceeded the minimum arbitrary limit of 45%.

3. If normal tension to shear strength ratios greater than 35% were required for welds in the 3/16-in. gage, it was found necessary to temper these welds by the passage of additional current, after a proper cool time, while the metal was still between the electrodes.

4. The recommended tempering conditions for exceeding the minimum arbitrary normal tension to shear strength ratio of 45% have been specified for the 3/16-in. material.

5. Vickers hardness traverses substantiated the selection of tempering conditions for the 3/16-in. gage material.

6. Sheet separation and indentation measurements did not exceed the arbitrary limits of 10 and 5%, respectively, for welds made with recommended conditions.

7. Electrode life was considerably lowered by the welding of scaly stock. It was found that electrode dressing was usually required after approximately 200 welds.

8. At the recommended welding conditions, expul-

sion of metal was usually present to some degree, indicating the need for protection of operators and passersby.

9. Even with recommended welding conditions, the consistency of weld strengths was only fair, the coefficient of variation being in the range of 5 to 10%.

10. The strengths of welds made in scaly material compared quite favorably with the weld strengths of grit-blasted stock.

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ACKNOWLEDGMENTS

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The New Bridge at Lanaye Over the Albert Canal

by R. Fougnies, H. Louis and P. Thys

THE new bridge at Lanaye over the Albert Canal in Belgium was opened Oct. 28, 1950. It is the first large bridge containing considerable amounts of welding that has been built in Belgium since the war, Fig. 1. In this abstract only the welding aspects will be discussed.

Abstract of "Le nouveau pont de Lanaye sur le Canal Albert," published in *L'Ossature Métallique*, 16, 155–168 (April 1951). Abstracted by Dr. G. E. Claussen.)

The steel for the riveted portions of the bridge, which include the upper and lower chords of the main trusses, is basic Bessemer steel. The steel for the welded portions, Table 1, is killed basic open-hearth steel in accordance with the specifications for welded structures of the Bridges and Highways Administration. The steel for welding was normalized at the mill and was supplied in four thicknesses:

Plates $^3/_8$ in. thick for webs of the longitudinal and transverse floor beams; for webs of the vertical members of the truss; and for webs and flanges of the upper stiffening beams.

Fig. 1 (a) View of the Lanaye Bridge

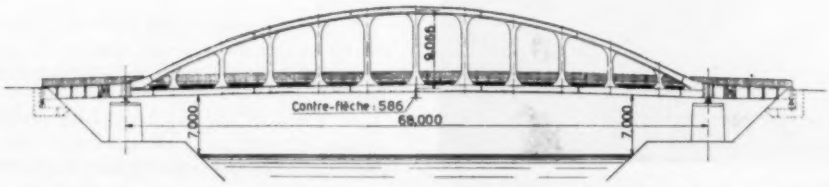

Fig. 1 (b) Elevation of the Lanaye Bridge. Dimensions in meters. The span is 222 ft., the camber being almost 2 ft.

Table 1—The Steels Used for the Welded Portions of the Bridge

	Plates 5/8 in. thick	*Ribbed flanges, 12 1/2 x 0.51 in. and 15 3/4 x 0.71 in.*	*Web plates, 8 x 0.71 in.*	*Ribbed flanges, 12 1/2 x 1 in. and 15 3/4 x 1 in.*
Elastic limit, psi.	39,800–44,700	36,100–37,100	38,000–40,700	40,700–41,100
Tensile strength, psi.	58,000–60,700	55,800–56,100	55,600–61,800	55,800–57,500
Elongation, %*	25.7–31.4	28.7–31.3	23.4–33.6	29.4–35.6
Notch impact value,† mkg./cm.²	12–24	20.4–24.1	15–27	24.4–27.3
Aged notch impact value,‡ mkg./cm.²	8–26	22–24.4	12–28	17.3–22.5
Carbon, %	0.09–0.14	0.11–0.16	0.10–0.11	0.11–0.14
Sulphur, %	0.031–0.036	0.032	0.028–0.040	0.026–0.031
Phosphorus, %	0.02–0.036	0.017–0.026	0.015–0.030	0.017–0.026
Manganese, %	0.43–0.60	0.506–0.580	0.42–0.51	0.52–0.58
Silicon, %	0.028–0.066	0.05–0.06	0.02–0.056	0.037–0.066

* Gage length = $\sqrt{66.67S}$, where S = cross-sectional area.
† Mesnager specimen.
‡ Aging consisted of the following treatment: 5% elongation in a tensile machine followed by heating 30 min. at 480° F.

Plates 0.51 in. thick: the ribbed flanges 12 1/2 in. wide for the transverse beams of the approaches.

Plates 0.71 in. thick: plates 8 in. wide for the webs of the vertical members of the truss, and ribbed flanges for the transverse floor beams.

Plates 1 in. thick: ribbed flanges for the floor beams of the bridge and approaches.

The steel has a high notch impact value after aging which usually is attributed to very fine grain size. However, it is our opinion that an entirely satisfactory explanation has yet to be offered. The greater scatter of impact results for the aged specimens compared with the as-received specimens is attributed to nonuniform distribution of the aluminum used to kill the steel. Bend tests were passed satisfactorily by every heat of steel both as-received and after quenching.

An over-all weldability test of the ribbed flanges 0.51 and 1 in. thick was conducted on full section static tension specimens with a rectangular notch cut in each face to reduce the cross section by 41 to 48%. Fractures were silky, not brittle, and the elongation was 22 to 25.7% on a gage length of $\sqrt{66.67S}$. Deep etch tests on each heat were satisfactory except for a few plates showing slight laminations, which were discarded. No laminations were detected during fabrication, neither during oxyacetylene torch cutting nor during welding.

Experience with shearing of ribbed flanges has not been satisfactory. The sheared ends are bent out of shape for a distance of up to 8 in. Certain plates for this bridge had to be straightened cold by the fabricator. Authorization for the straightening was given only in consideration of the excellent quality of the steel. The Administration now permits flame cutting of the ribbed flanges.

The fabricator used 3/16- and 1/4-in. contact C20 electrodes for welding. Ordinarily 5/32-in. electrodes are required for the first pass of fillet welds to assure complete fusion at the root. However, in view of the high penetration of the C20 electrodes (about 300 amp. is used) the minimum diameter of 3/16-in. was approved. The approval tests, Table 2, were satisfactory except for the notch impact value of the 1/4-in. size, which fell below the specified minimum of 10 mkg./cm.² A retest was more satisfactory, the Mesnager values ranging from 11.2 to 13.25 mkg./cm.² for six specimens. Bend tests (pin diameter = twice the plate thickness) on as-welded specimens were successful for both diameters of electrode. However, bend tests on quenched specimens (pin diameter = three times the plate thickness) welded with 1/4-in. electrodes failed at an angle of 90°. Of two repeat specimens, one could be bent flat without failure, while the other exhibited a crack and a fusion line failure at 180°. The ability of the electrode to penetrate the apex of a fillet was checked by macrosections. Radiographs of all the butt joints for approval test showed no gas or slag inclusions. Yet the surface of bend specimens that had been bent flat contained tiny defects. These defects are believed to be related to fish eyes, for the tensile specimens contained several fish eyes in the fracture of the weld metal.

The qualification test for the welding operators consisted of penetration and bend specimens. The penetration specimens were fillet welds, while the bend specimens (pin diameter = twice the plate thickness) were V butt welds bent to 180°. Both face and root specimens were bent. The bend tests had to be repeated several times, because the operators were not accustomed to the electrode and there were numerous fish eyes in the welds. As in the approval tests of the weld metal, flakes near the surface of a bend specimen tended to favor failure. Many of the butt joints in the bridge were radiographed but no defects were found sufficiently large to require chipping. One peculiarity of these electrodes should be corrected. The craters

Table 2—Approval Tests of the Electrodes Used to Weld the Bridge

Diameter of electrode	*3/16 in.*	*1/4 in.*
Elastic limit, psi.	55,500	50,800
Tensile strength, psi.	69,800	66,100
Elongation, % in 3 in.	25.7	25.7
Reduction of area, %	56.4	60
Mesnager notch impact value, mkg./cm.²	10.6-10.75-10.1	8.6-10.9-9.4
Carbon, %	0.12	0.10
Sulphur, %	0.018	0.02
Phosphorus, %	0.055	0.049
Silicon, %	0.132	0.117

The test plates were allowed to cool below 300° F. between layers.

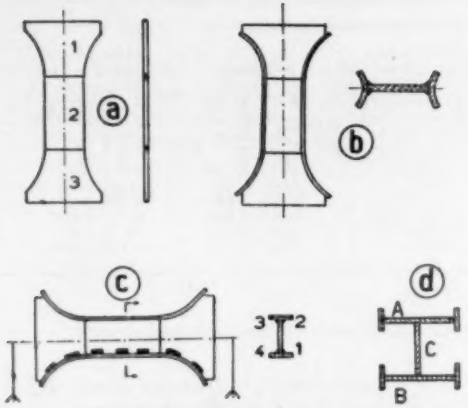

Fig. 2 Procedure in welding the vertical members

are about an inch long, are deep and are difficult to fill. Every crater acts as a notch under shrinkage stresses.

The vertical members of the trusses were assembled in three operations, Fig. 2. These members, which are riveted to the upper and lower chords, consist of three web plates, Fig. 2 (*a*), butt welded together with double-vee welds. These joints are welded alternately from both sides to avoid angular distortion and have run-off plates to avoid craters. The run-off plates are removed by flame cutting. The second operation consists of welding the flanges, Fig. 2 (*b*). The prebent flange plates (8 x 0.71 in.) are tacked to the web, Fig. 2 (*c*). The first pass is made in the horizontal position with the web in the vertical plane. Two operators weld simultaneously, one on each side of the web. The fillets are deposited in the order 1, 4, 2, 3, using back step procedure starting from the middle of the beam and progressing symmetrically toward each end. Thus the ends of the welds are made in the semivertical down position. After the first layer of each weld was deposited, the beam was turned so that succeeding layers were welded in the flat position (web and flange each 45° to the vertical), except for the extreme ends of the welds, which were again in the horizontal position. The fillets were built to a throat dimension of 0.20 in. The flanges projected $^3/_8$-in. beyond the web to permit the fillet welds to be turned round the end of the web, in this way preventing cracks. The third operation consisted of joining two tee beams made in the first two operations to a third, central web, Fig. 2 (*d*). Beams *A* and *B* were tacked in position on web *C*, then were clamped. Because fillet welds exert little transverse restraint, clamping does not involve serious consequences. The same rotating jig was used as for the second operation, and symmetrical welding also was

Fig. 3 Assembly of one of the trusses and the upper stiffening box beams

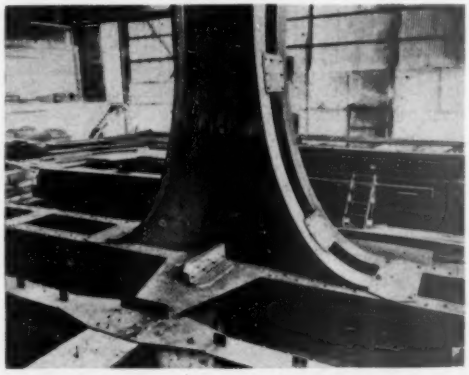

Fig. 4 A view of a vertical member riveted to the lower chord and a transverse floor beam

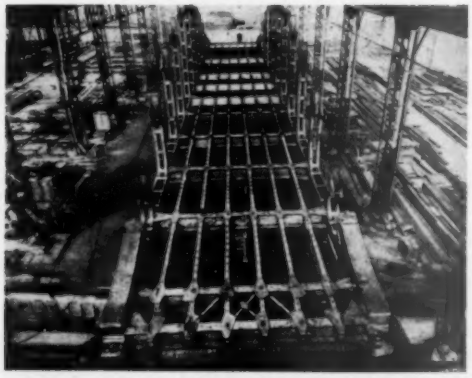

Fig. 5 Assembly of floor beams, lower chords and vertical members

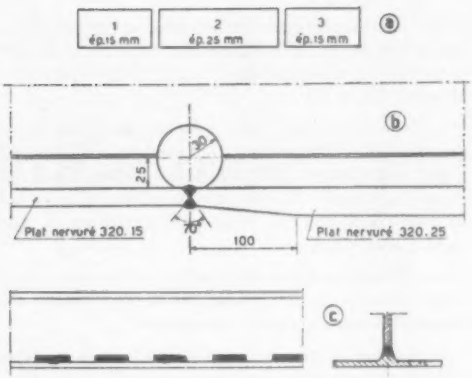

Fig. 6 Steps in welding the transverse floor beams. Dimensions in millimeters

arranged. Three views of the vertical members are shown in Figs. 3, 4 and 5.

The transverse floor beams consist of a $^{3}/_{8}$-in. web with ribbed flanges 1 in. thick in the central portion and 0.51 or 0.71 in. thick at the ends, Fig. 6. First the flange plates were butt welded, Fig. 6 (*a*), the rib being cut away at the joint to permit good welding, Fig. 6 (*b*). Run-off plates were used at each end of every butt to eliminate craters. Welding was performed symmetrically from each side. The flanges then were tacked to the beveled web plate. The inclination of the flanges at the ends to match with the camber of the lower chord of the truss was regulated by patterns. Starting at the middle of each beam, one welder on each side of the web deposited a bead back step fashion toward each end, Fig. 6 (*c*). Particular attention was paid to freedom from undercut, and to secure a slightly concave weld contour.

In concluding this discussion of the transverse floor beams it may be well to observe that ribbed flanges are well conceived for welded construction but involve serious difficulties. First, the dimensional tolerances on the rib are too great so that the rib is not the same height on different plates. As a result the web plate must be cut to fit, which is difficult and expensive. Furthermore, the maximum eccentricity of the rib is too great, which makes it difficult if not impossible to butt two plates of the same width together. There is always a serious and ugly notch at the junction. Again the rib is not always straight and its curvature may even change direction on the same plate. As a result it was difficult to secure good welds of web to rib. Finally, the rib should be higher than present tolerances allow if the ribbed flange is to serve its real advantage.

The longitudinal floor beams were welded according to the same plan as the transverse. The riveted joint connecting longitudinals to a transverse is shown in Fig. 7.

The beams serving to stiffen the upper chords of the

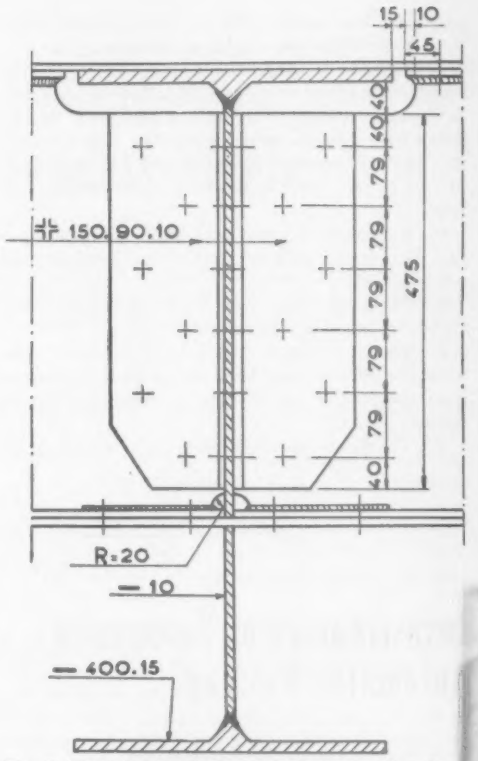

Fig. 7 Riveted joint between a transverse floor beam (in cross section) and through longitudinal

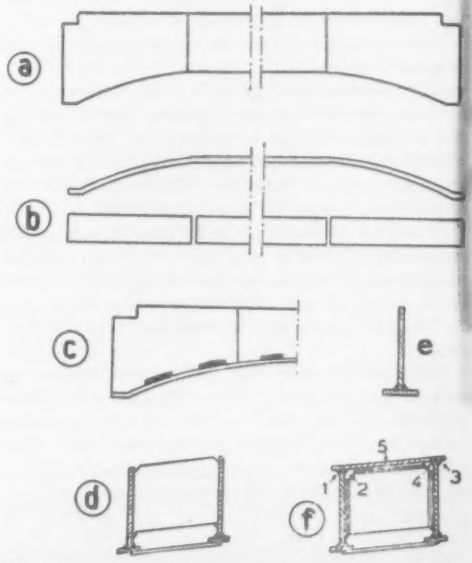

Fig. 8 Steps in welding an upper stiffening box beam

bridge are box sections, Fig. 8. They consist of two 3/8-in. webs of variable height, an upper flange 21 x 3/8 in., and two lower flanges 6 x 0.55 in., Fig. 8 (*f*). The flanges are inclined to the web to follow the curvature of the upper chord. The lower flanges were tied together by occasional small plates 10 x 0.32 in., while the web separation was maintained by diaphragms 14 1/2 x 3/8 in. The box beams were fabricated in six steps.

1. Butt weld the three sections of each web, Fig. 8 (*a*). Double vee welds were welded symmetrically with run-off plates.

2. The lower flanges were welded in the same way, Fig. 8 (*b*), from three plates.

3. The lower flanges were tacked and welded to the webs, Fig. 8 (*c*), using back step procedure, starting from the middle and welding symmetrically toward the ends.

4. The diaphragms were tacked and welded to the webs. The diaphragms were intended to prevent buckling of the webs. The diaphragms were not extended to the lower flanges, in order to avoid needless junctions of welds, Fig. 8 (*d*).

5. The reinforcing plates were applied to the lower flanges. The plates were not butt welded, which would have required butt welds the roots of which could not be reverse welded. Instead, the plates were fillet welded to the flanges, and the fillets were turned around the ends of the plates.

6. The upper flange was tacked and welded to the webs in the order 1, 2, 3, 4, Fig. 8 (*f*). Finally the flange-diaphragm weld was completed.

In conclusion, the majority of the butt welds were carefully finished and were radiographed by the fabricator La Compagnie Centrale de Construction of Haine-Saint-Pierre, Belgium. None of the welds exhibited defects sufficient to require repair.

Investigation of Submerged Automatic Welding*

by L. N. Kushnarev

A SYSTEMATIC investigation of the process of submerged automatic welding was conducted with extensive use of an oscillograph of the type of the hexavibratory device developed by the firm of Siemens & Halske.

Oscillographic recording of the arc burning under the flux extended over a range of welding currents of from 200 to 1500 amp.; the arc voltage was varied within wide limits, that is, much wider limits than is customary under normal conditions. The oscillograms were recorded by the so-called shunting method.

In order to account for the influence of composition and quality of the flux upon the burning of the arc, oscillograms were secured during welding under different fluxes, and for purposes of comparison, also during welding with an unprotected arc and an arc in a gas envelope.

The layer of molten flux ensuring a protective slag blanket is endowed with a low thermal conductivity. While the flux consumes a certain part of the arc energy for its fusion, it maintains a uniform temperature in the molten metal and by preventing dissipation of heat into the surrounding air, it helps concentrate the heat in the electrode gap.

The nature of the variation in the shape of the curve relating to the voltage between the electrode and the work in submerged automatic welding differs considerably from the character of the voltage with an open arc, in the majority of cases. The voltage curves of an arc burning under a flux vary quite smoothly; there are no high-frequency fluctuations nor are there any peaks of re-ignition so characteristic of the voltage of an arc burning in a hydrogen atmosphere or in an open arc.

GENERAL CONCEPT REGARDING THE PASSAGE OF THE CURRENT IN SUBMERGED AUTOMATIC WELDING

In the light of our observations as to the process of welding and on the basis of an analysis of the oscillograms, the path of passage of the current in submerged automatic welding must be assumed to depend on the conditions of welding. With currents of 300–400 amp., small spacings between electrode and piece, and a low welding speed, the electrode is usually immersed directly in the molten flux. At a high temperature, the flux possesses a sufficiently high electrical conductivity and, hence, as the current passes through it, the voltage drop between electrode and workpiece may be less than the voltage required for forming the arc; in this case, no arc is observed and fusion of the base metal and the electrode metal will be due to the heat produced by the passage of the current through the flux.

If conductivity is only through the flux, the curve relating to the voltage between the electrode and the workpiece shows a sinusoidal shape. For certain lengths of time, it may happen that conductivity of the flux alternates with conductivity of the arc.

(*Continued on page 347-s*)

* Extracts from a translation from Avtogennoe Delo, 18 No. 3, 5–9 (1947) by Henry Brutcher, Technical Translations, P. O. Box 157, Altadena, Calif. Complete copies available from Mr. Brutcher at $8.90 per copy.

Welding Copper-Bearing Stainless Steels

Properties of weldments and effects of composition, heat treatments, welding technique, and welding processes of various commercial and experimental welding electrodes developed here and abroad

by Helmut Thielsch

SUMMARY

Copper additions are generally made to chromium and chromium-nickel stainless steels to increase their corrosion resistance to many environments and/or to provide age-hardening properties.

Although copper is readily transferred from the electrode to the weld deposit, the element sometimes produces undesirable effects in a number of alloys because of its tendency to precipitate in the form of copper-rich alloy phases.

The martensitic and ferritic copper-bearing chromium stainless steels generally are welded with standard (copper-free) 25–12 or 25–20 (Cr-Ni) electrodes. The higher alloy content of the resulting weld metal in most corrosive applications sufficiently compensates for the advantages offered by the presence of copper in the chromium stainless steel.

Austenitic copper-bearing chromium-nickel stainless steels usually are welded with electrodes which have compositions similar to the base steel. In the absence of ferrite in the weld metal, the weld deposits are generally crack sensitive under restrained conditions. Cracking under unfavorable welding conditions can normally be prevented by careful control of the electrode composition, proper welding technique [use of low welding currents, short arcs and cooling the weld metal between deposits to below 400° F. (205° C.)] and, sometimes, by preheating the joint.

Since the carbon content in the austenitic stainless steels is usually kept below 0.07%, welding alone generally does not produce sufficient intergranular carbide precipitation to make the steel susceptible to intergranular corrosion in service. However, exposure of these steels and weldments at intermediate temperatures, at which chromium carbides would ordinarily precipitate intergranularly, would require the addition of stabilizing elements, such as columbium, tantalum or titanium, to the steel and columbium and/or tantalum to the electrode.

INTRODUCTION

THE copper-bearing stainless steels represent a relatively new group of stainless alloys. Although in certain applications these steels offer superior properties over other commercial stainless-steel grades, the physical metallurgy of many alloys is relatively complex* and thus has, until recently, retarded the commercial development of these alloys.

Copper additions are generally made to stainless steels to increase their resistance to certain corrosive environments, to decrease susceptibility of stainless steels to stress-corrosion cracking or to provide age-hardening properties. In the last case, the combined properties of good corrosion resistance and age hardening are often desired.

From a commercial point of view the copper-bearing stainless steels may be divided into four major groups:

1. The martensitic or ferritic copper-bearing chromium stainless steels contain up to 30% chromium, between 0 and 3% nickel and up to 1% copper. These alloys are primarily used for corrosion resistance in condenser tubes, in marine and other sea-water applications and in food equipment.

2. The copper-bearing austenitic (partially ferritic) stainless steels primarily contain up to about 25% chromium, between 3 and 10% nickel and up to 4% copper. These steels are generally used as age-hardening alloys at room or at intermediate temperatures up to about 600° F. (315° C.). Typical examples of these alloys are found in gears, cams, pinions, valve plugs and in other parts employed in applications which require a combination of good age-hardening characteristics with high corrosion resistance.

3. The medium nickel fully austenitic stainless steels (12 to 30% chromium and 10 to 20% nickel) usually contain about 2 to 4% copper. These steels are generally used as age-hardening alloys for applications at elevated temperatures up to 1500° F. (815° C.). Typical applications are in gas and steam turbines, superheaters, etc.

4. The high-nickel fully austenitic stainless steels generally contain 15 to 30% chromium, 20 to 35% nickel and 2 to 5% copper. These alloys are primarily used in applications which require superior corrosion

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This report was prepared under the auspices of the Literature Advisory Committee of the Welding Research Council. G. E. Doan, *Chairman*; T. S. Fuller, L. E. Grinter, C. E. Jackson, E. M. MacCutcheon, R. F. Miller, W. Spraragen, David Swan, R. David Thomas, Jr., J. L. Walmsley and Helmut Thielsch, *Secretary*.

* A detailed discussion of the physical metallurgy of the copper-bearing stainless steels is published by the Welding Research Council in a separate report as Welding Research Council Bulletin No. 9, *Copper in Stainless Steels, August 1951*. This report discusses phase relations, hot-working properties, corrosive properties, age-hardening characteristics of the various types of copper-bearing stainless steels containing up to 30% chromium and between 0 and 35% nickel and other alloying elements such as Mo, Si, Mo, Cb, Ti, W, Be, V, etc. Tables listing the various patented and commercial alloys are also included.

resistance to solutions or slurries containing sulphuric, acetic and other generally reducing types of acids.

WELDING CHARACTERISTICS

Ordinarily the amount of chromium and/or nickel in the stainless grades determines whether the structure of the steel is primarily martensitic,[4] ferritic[4] or austenitic.[2,3] The addition of copper complicates the phase relations in that many alloys, after exposure to certain temperatures, tend to precipitate copper-rich alloy phases. Moreover, many commercial alloys may also contain various other alloying elements such as molybdenum, silicon, columbium, etc. These may further influence the phase relations either by changing the quantity of the copper-rich phases precipitating or by introducing additional alloy phases. Thus weld deposits of certain compositions may exhibit several structural constituents. For example, in a 20/20/3/4 Cr/Ni/Mo/Cu† weldment, a copper-rich alloy phase tends to appear well segregated in the dendritic pattern. This is apparent from Fig. 1 which shows the alloy phase in the weld metal and in the heat-affected zone of the wrought base steel of the same type of composition. Whereas this and other possible phase constituents may not produce adverse effects in a number of alloys when exposed to certain corrosive environments, other environments might be highly detrimental to some of these phases and may seriously affect the serviceability of the alloy. Thus control of electrode composition may be highly important for many alloys. Moreover, particular heat treatments may be necessary to improve the structure of these steels or to produce other desirable effects.

In general, the copper-bearing steels are particularly suited to welding operations.[5] This is primarily related to the fact that copper is not easily oxidized out of the molten weld metal. On the other hand, the more highly alloyed austenitic copper-bearing stainless welding compositions are often crack sensitive and, in sections of high restraint, may show cracks in the weldment. This may necessitate careful control of the welding procedure.

Stainless Steels Containing Up to 3% Nickel

Depending primarily upon the chromium and carbon content, these steels may be either martensitic or ferritic or both. In addition, the presence of some nickel may allow the retention of austenite in the matrix structure.

The martensitic (hardenable) copper-bearing stainless steels, which usually contain up to about 16% chromium and no nickel, have to be welded with care because the severe hardening, which occurs as a result of the austenite-martensite transformation, leaves large residual stresses. These often result in cracking of the already brittle martensite. Cracking may be minimized by preheating these steels at temperatures between 600 and 800° F. (315 and 425° C.) prior to welding. A postheat treatment between 1200 and 1400° F. (650 and 760° C.) should immediately follow the welding operation if ductile welds are desired. This postheat treatment should also remove the effects of age hardening which occur as a result of the preheat treatment. When these steels are to be used in the hardened condition, the postheat treatment may be omitted.

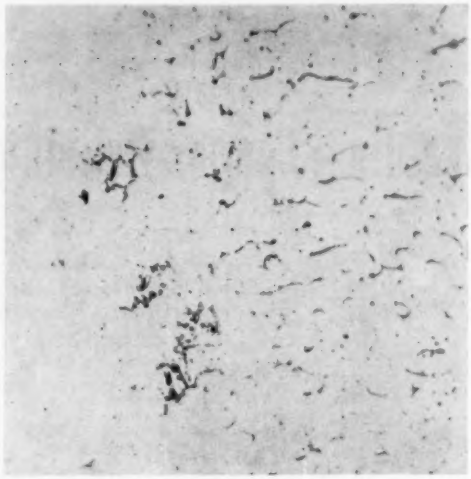

Fig. 1 Fusion zone in 20/29/3/4/ Cr/Ni/Mo/Cu weldment. Electrolytic etch 10% HCl in alcohol. Magnification 500 ×

Because these steels are generally used in corrosive applications, electrodes of composition similar to the base stainless steels are generally preferred. However, in many mildly corrosive applications the martensitic or ferritic stainless steels are welded with standard 25–12[6] or even with 25–20 (Cr-Ni) electrodes which do not contain copper. When these austenitic electrodes are used on steels which cannot receive preheat and/or postheat treatments, it is advisable to select small diameter electrodes to minimize heating of the hardenable parent metal.

Stainless Steels Containing 3 to 10% Nickel

These alloys may be martensitic, ferritic, ferritic-martensitic, ferritic-austenitic or austenitic. The quantity of martensite or of retained austenite at room temperature primarily depends upon the nickel content. For example, steels with up to 16% chromium and up to 4% nickel will be martensitic. Higher percentages of chromium and/or nickel will cause increasing proportions of austenite to be retained at room temperature.[4] Martensite is not likely to be present in copper-bearing stainless steels with over 6% nickel. However, some ferrite may be retained on

† To distinguish the copper-bearing stainless steels from the standard A.I.S.I. types, the former are represented as Cr/Ni/Mo/Cu (separated by a diagonal) whereas the A.I.S.I. grades are written as Cr-Ni (hyphenated).

cooling from elevated temperatures. Because these steels generally are highly alloyed, prediction of their microstructure from composition alone is often quite difficult.

Since the alloys with 3 to 5% nickel may exhibit a structure containing some martensite in addition to ferrite and/or austenite, it is important that the physical metallurgy of each particular composition be understood. This is particularly true since various other alloying additions may modify the effects of nickel and chromium.

If martensite is present, preheating between 600 and 800° F. (315 and 425° C.) is generally advisable. Moreover, if ductile and tough welds are desired, a postheat treatment between 1200 and 1400° F. (650 and 760° C.) should follow directly after the welding operation without cooling the section. On the other hand, if wear, a high tensile strength and a high elastic limit are important, postheat treatments may not be necessary. In general, the welding recommendations, which have been previously discussed, should be followed.[4]

Preheating may not be required in these ordinarily martensitic compositions when hardening of the heat-affected zone is minimized by keeping the carbon content as low as possible—preferably below about 0.07%. Thus welded joints of an age-hardening 17/4/0/4 Cr/Ni/Mo/Cu alloy containing:

	%
C	0.05
Cr	16.5
Ni	4.0
Cu	4.0

did not exhibit hardening in the welded joint as a result of martensite formation.[19] Moreover, little or no precipitation hardening occurred because the thermal cycle of welding was too short.[19]

The effects of welding and heat treatments on age-hardenable 17/4/0/4 Cr/Ni/Mo/Cu alloys are shown in Table 1. The annealing heat treatment consists of ½ hr. at 1800 at 1900° F. (980 to 1040° C.). Hardening is usually accomplished in about 1 hr. at 900° F. (480° C.)

The most efficient method of age hardening the 17/4/0/4 Cr/Ni/Mo/Cu alloy is to apply the annealing and hardening treatments after welding.[19]

Fully austenitic weld deposits containing 8 to 19% nickel generally are somewhat crack sensitive and exhibit poor mechanical properties. Composition is highly important. For example, in fully austenitic weld deposits, it generally seems desirable to limit the silicon content to between 0.3 and 0.5%. However, for best results, the composition of the electrode should be adjusted so that the deposited weld metal contains about 5 to 15% ferrite. Moreover, if some ferrite is present, higher percentages of silicon may be tolerated.[2]

Thus although the copper-bearing stainless steel which is to be welded may not contain ferrite, the weld metal should preferably be partially ferritic. For example, partially ferritic copper-bearing stainless electrodes were preferred for welding large 18–13–1 (Cr-Ni-Cb) disks to form rotors for land gas turbines as well as for welding stainless-steel pipes for power stations where temperatures and pressures are being increased.[7]

According to Rollason[7] one solution to this problem, where a stabilized weld is required at elevated temperatures, has been the use of a 18/8/0/2 Cr/Ni/Mo/Cu electrode carefully balanced with 1% columbium. The ferrite content is about 3 to 5% which is sufficient to prevent microcracking. Columbium prevents intercrystalline corrosion, whereas the copper is believed[7] to retard very considerably the formation of the sigma phase and, consequently, to prevent the resultant sigma-phase embrittlement. Typical properties of the weld are given in Table 2.

The ductility of the columbium-bearing 18/8/0/2 Cr/Ni/Mo/Cu weld metal is ample for most applications.[7] It has been found, however, that although microcracks do not occur during deposition, certain prior heat treatments of the weld metal when followed by further welding can cause cracks. A stress-relieving treatment at 1560° F. (850° C.) should, therefore, be avoided if further welding is to be done. The heating effects resulting from multibead deposits generally are not detrimental since copper diffusion to the grain boundaries and the formation of an intergranular precipitate of a copper-rich phase require heating periods in excess of those resulting from welding operations.[7]

Table 1—Mechanical Properties of Welded Joints in 17/4/0/4 Cr/Ni/Mo/Cu Age-Hardenable Stainless Steel Prepared by Metal-Arc* Welding or Inert-Gas† Welding[19]

Treatment	*Hardness Rc* — *Base steel*	*Hardness Rc* — *Weld metal*	*Tensile strength, psi.*	*Elongation % in 2 in.*	*Location of fracture*	*Efficiency of weld based upon tensile strength, %*
Annealed, hardened (not welded)	43	...	200,000	10.0	.....	...
Annealed, hardened and welded	43	30	150,000	5.0	Weld metal	75
Annealed, welded and hardened	43	44	185,000	6.0	Weld metal	92
Welded, annealed and hardened	43	43	195,000	5.5	Weld metal	98
Annealed, hardened, welded and hardened	43	45	185,000	7.2	Weld metal or heat-affected zone	92

* Double-bevel butt joints in 1/4-in. thick plate prepared by metal-arc welding with 5/32-in. size flux-coated electrodes.
† Square-butt joints in 1/4-in. thick plate prepared by argon-shielded tungsten-arc welding using one pass on each side and adding no filler metal.

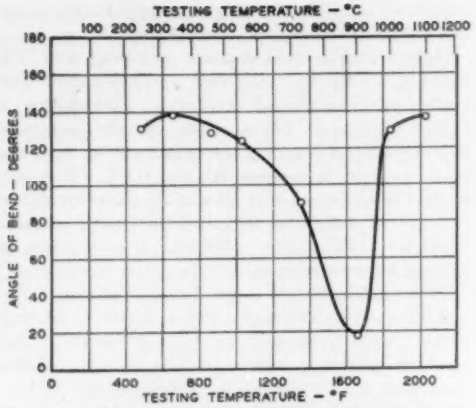

Fig. 2. Bending properties at elevated temperatures of 18/8/0/2 Cr/Ni/Mo/Cu weld metal[7]

To elucidate this problem further, a number of bend tests have been made by Rollason[7] at different temperatures. The results are shown in Fig. 2. It will be seen that the ductility begins to decrease at 1380° F. (750° C.) and is very low at 1650° F. (900° C.) after which the ductility again increases rapidly. Provided that sufficient time has been allowed at 1560 to 1650° F (850 to 900° C.), subsequent underbead heating is liable to cause cracks if restraint is present.[7]

When corrosive resistance is of primary importance, molybdenum is usually added to the composition. Since molybdenum acts as a ferrite former,[2,3] the composition is generally balanced by increasing the nickel content to between 10 and 11%.

Early German experiments on the effects of different electrode compositions on the mechanical properties of stainless steels used for applications in corrosive environments are reported in Table 3.[9] These initial studies led the investigators to believe that the addition of 0.5 to 0.6% titanium to the electrode is beneficial.[9] Although it is obvious that most of the titanium is lost by oxidation during welding, the remaining titanium was nevertheless responsible for a very fine grain size in the steel.[9] This grain refinement helps to produce weld deposits free from cracks. The compositions finally suggested by Krupp in 1941[9] and subsequently established in Germany up to 1949[10] are listed in Table 4.

Because of the availability of columbium (1950), these titanium-bearing electrodes are not currently manufactured in Germany and the steel (V46A Extra), from which the electrodes had been made, has been discontinued.[11]

At present, an electrode of the following composition is commercially produced in Germany:[11]

	%
C	0.10 max.
Mn	0.8–1.2
Si	2.2–2.6
Cr	17.5–18.5
Ni	9.0–10.0
Mo	1.8–2.2
Cu	1.8–2.2
Cb	>8 × C

Although it is generally desirable to keep the silicon content low, the weld metal from this electrode is likely to contain ferrite and, consequently, may tolerate this higher silicon content.[2]

In France a titanium-bearing electrode is produced at the present time which contains:[20]

	%
C	0.09 max.
Si	0.4
Cr	17.5
Ni	11.0
Mo	2.5
Cu	0.5
Ti	4 × C

The electrode is used to weld a stainless steel of similar composition.[1]

Stainless Steels Containing 10 to 20% Nickel

The presence of 10 to 20% nickel generally prevents the formation of ferrite. Thus these medium nickel stainless steels are considered to be essentially austentic in structure. However, small quantities of a copper-

Table 2—Mechanical Properties of Columbium-Bearing 18/8/0/2 Cr/Ni/Mo/Cu Weld Metal[7]

Composition, %							*Tensile strength, psi.*	*Elongation, % in 2 in.*	*Reduction in area, %*	*Izod impact toughness, ft.-lb.*
C	*Si*	*Cr*	*Ni*	*Cu*	*Cb*	*Treatment*				
0.07	0.2	18.1	8.3	2.2	0.78	As-welded	74,000	40	55	35, 45, 35
						300 hr. at 1200° F. (650° C.)	85,000	35	37	24
						5000 hr. at 1200° F. (650° C.)	86,000	31	28	11

Creep at a stress of 10,000 psi. at 1200° F. (650° C.) is 0.090% with a second-stage creep rate of 5.7×10^{-7} in./in./hr.

Table 4—Electrode compositions recommended by Krupp[9] and subsequently established in Germany[10]

	Composition, %						
	C	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*Cu*	*Ti*
Krupp Alloy (1941)	0.08	0.8–1.0	0.8–1.0	17–18	9–10	2.35–2.65	2.8–3.2	0.5–0.6
German Welding Practice (1949)	0.07 max.	0.2–0.4	0.3–0.5	17.5–18.5	9.5–10.5	1.8–2.2	2.8–3.2	7 x C

rich alloy phase and of other phases may be present in some of the more highly alloyed compositions.

Weld deposits from stainless steels containing between 10 and 20% nickel are not likely to show ferrite. Thus crack-sensitive weld deposits may be expected unless the composition of the electrode is carefully controlled. The susceptibility to cracking of fully austenitic weld deposits has been discussed in a previous article.[8]

Control of silicon content seems to be of considerable importance. Thus good results seem to be obtained when the silicon content remains between 0.3 and 0.5%. For example, good mechanical properties of a 16/14/3/3 Cr/Ni/Mo/Cu type weld deposit containing:

	%
C	0.115
Mn	0.78
Si	0.43
Cr	16.26
Ni	14.22
Mo	2.70
Cu	3.12
Cb	0.74

are reported in Table 5.

Similarly, 18/8/2/2 Cr/Ni/Mo/Cu type electrodes manufactured by Böhler, A. G. (Fox SAS 8) and the Deutsche Edelstahlwerke, Bochum (Thermanit E) specify a narrow silicon range. These electrodes have the following composition:[10]

	%
C	0.07 max.
Mn	0.2–0.4
Si	0.3–0.5
Cr	17.0–18.0
Ni	17.0–18.0
Mo	1.8–2.2
Cu	1.8–2.2
Ti	7 × C

Although very little of the titanium addition would pass into the weld metal,[9] it should serve to produce a fine grain size. This is believed to be beneficial in reducing sensitivity to cracking. The upper limit of 2.2% copper may be chosen to minimize (or eliminate) the formation of copper-rich phases in the dendritic weld metal.

With the exception of titanium, the same range of composition reported in the above table also applies to another German steel except that the titanium content is replaced by columbium amounting to 12 times the carbon content.[11]

In welding 18/18/3/3 Cr/Ni/Mo/Cu alloys it is necessary to avoid excessive heating of the base steel adjacent to the weld, since this can cause grain growth and embrittlement in this area.[12] This refers par-

Table 5—Tensile Test Results of Standard A.S.T.M.-A.W.S. All-Weld-Metal Specimens[12]

Specimen	*Tensile strength, psi.*	*Yield strength, psi., 0.2% offset*	*Elongation % in 2 in.*	*Comments*
1	89,400	64,300	30.0	No cracking
2	88,600	66,500	31.0	No cracking

Table 3—Mechanical Properties of Weld Deposits in the As-Welded Condition from Copper-Bearing 18-8 (Cr-Ni) Electrodes[9]

Electrode designation	*Composition,* %*										*Mechanical Properties*				
	C	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*Cu*	*Cb*	*Ta*	*Ti*	*Yield strength, psi.*	*Tensile strength, psi.*	*Elongation % (L = 5d)*	*Reduction of area, %*	*Impact toughness, mkg./sq. cm.*	*Appearance of fracture*	*Appearance of weld bead*
V6 A-E X	0.05	0.53	2.00	18.3	9.0	...	2.08	1.1	0.81	0.47	66,500	93,400	33.5	44	6.6	Fine grained	Many cracks
											66,500	92,000	32.6	47	6.6		
V46 A-X	0.09	1.44	1.47	18.6	8.85	2.54	3.1	0.80	0.74	...	71,100	99,000	27.0	28	8.0	Fine grained	Bead crack about 0.2 in. long
											68,300	99,000	[33.0	49	9.0	Fine grained	Crater crack about 0.2 in. long
V46 A-E X	0.06	1.49	1.53	19.0	9.0	2.57	3.1	1.21	0.86	0.31	71,100	101,000	32.0	49	7.0	Fine grained	Crack free
											71,100	99,000	33.0	44	6.3		
V46 A-E X	0.05	1.48	1.83	18.9	8.9	2.62	2.95	1.16	0.81	0.39	71,100	103,200	23.0	40	5.3	Fine grained	Crack free
											68,300	103,200	26.7	40	5.4		
V 6 A-X†	0.07 max.	...	...	18.0	8.0	...	3.0	1.0	...	...	55,200	49,500	2.0	...	6.1	...	Many cracks
												60,900	4.0	17	5.6		

* Core wire analyses.
† Type composition.[11]

ticularly to oxyacetylene welding where the "burn-up" of heat is more pronounced than with other processes.

Stainless Steels Containing Over 20% Nickel

These alloys generally have a fully austenitic matrix. However, many compositions may also form other alloy phases such as the sigma phase, a copper-rich alloy phase, etc. In addition, intergranular carbide precipitation may occur if a stabilizing element has not been added.

In these alloys, the presence of a few per cent of copper considerably improves the corrosion resistance. Because molybdenum minimizes pitting and provides considerably increased resistance to sulphuric, acetic and other acids, a few per cent of this element are also added to most of the commercial copper-bearing stainless steels which are used in these environments.

In welding, it is generally highly desirable that the weld-metal composition is similar to that of the base steel. The reason is that these alloys are generally used in relatively active corrosive solutions in which the common 18–8, 25–12, 25–20 and 15–35 (Cr-Ni) austenitic grades are not considered practical.

The weld metal of these highly alloyed austenitic stainless alloys generally is susceptible to cracking. Thus considerable care should be taken when welding restrained joints and heavy sections such as, for example, are common in castings. Ordinarily, the following welding sequence is recommended:

1. Use low welding currents and a short arc. For example, for $^1/_8$-, $^5/_{32}$-and $^3/_{16}$-in. electrodes, the current should not exceed 90, 150 and 175 amp., respectively.[15]

2. Allow sufficient time between passes for the heat of the previous bead to be dissipated by conduction into the base metal. The temperature in the vicinity of the weld should preferably drop to about 300 to 400° F. (150 to 205° C.) before the next bead is deposited.[15] Moreover, in highly restrained sections, it may often be advisable to use a preheat treatment at about 400° F. (205° C.) in order to minimize cracking in the initial bead.

3. Stringer beads without weaving seem to be preferred generally.[15]

4. Any crater cracks which form in a deposited bead must be chipped out before the next bead is laid. The final crater may best be eliminated by running the last bead out onto the base steel and by removing the build up by chipping.[15]

Although arc welding is generally preferred, satisfactory weldments can also be made with the oxyacetylene, atomic-hydrogen and inert-gas welding processes.[15] Because temperature control is generally more difficult with these processes than with arc welding, weld deposits from these processes are believed to be more susceptible to cracking.[15]

Sometimes special welding procedures have to be used. For example, it was exceedingly difficult to produce welds which would meet X-ray inspection and root bend tests in weldments on $^3/_8$-in. thick 20/29/3/4 Cr/Ni/Mo/Cu plates which were formed and then manually arc welded with 20/29/3/4 Cr/Ni/Mo/Cu electrodes to make pipe.[14] Satisfactory root bends were finally produced by flowing argon through the pipe while the weld was being made. However, after the welded pipe was made, it was fairly readily formed into standard "long radius" welding ells.[14]

In structures in which high restraint, which cannot be overcome by careful control of the welding procedures, causes cracking in the weld deposit, it may sometimes be necessary to use special welding electrodes which produce a partially ferritic weld deposit.

In repair welding, the defective area must be removed and suitably beveled before any build-up is attempted. If the cavity is deep enough so that multilayer welding is necessary, the successive layers should preferably be kept horizontal.[15]

Although composition plays an important role in affecting the crack sensitivity of austenitic weld deposits,[3] it is yet too early to draw definite conclusions as to the effects of any particular element. Nevertheless, a silicon content above 0.50% may be expected to be highly undesirable because of the severe crack sensitivity induced by excessive silicon in austenitic weld deposits. That is why those alloys which contain over 1% silicon are not ordinarily recommended for fabrication by welding. Since these high-silicon stainless alloys are generally produced in the form of castings, the usual run of casting defects may be repaired by arc welding without undue difficulty.[15]

When maximum corrosion resistance is desired, a final annealing heat treatment between 1950 and 2050° F. (1065 and 1120° C.) followed by water quenching is generally recommended.[15,16,18] Such treatments, however, are impractical for many finished structures. Moreover, a finished surface takes on a slight scale during the heat treatment. Also, some warping may occur, which in machined parts may require some remachining.[15]

The necessity of final heat treatments considerably depends (1) upon the microstructure of the weldment which, in turn, is primarily a function of composition and (2) upon the characteristics of the solution or slurry to which the steel is exposed in service. In many applications, final heat treatment of weldments in the as-welded condition may not be necessary.

Exposure at intermediate temperatures may cause undesirable intergranular carbide precipitation—unless the alloy has been stabilized with columbium, titanium or tantalum. Since the majority of the commercial grades do not contain over 0.07% carbon, arc welding itself generally does not produce sufficient intergranular carbide precipitation to make the steel susceptible to intergranular corrosion in service.

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Investigation of Submerged Automatic Welding

(*Continued form page 340-s*)

With high currents, the electrode is deeply immersed in the base metal; in the space between the electrode and the base metal, there is generated a large volume of gases and an increased pressure. The molten flux is therefore forced away from the electrode; the value of the flux conductivity falls off, and the arc conductivity is in the ascendancy. The arc process, no doubt, deserves preference, as it ensures more intense fusion of the base and the electrode metal because of the high concentration of heat and the lower dispersion of current through the flux.

The process taking place under the flux may be thought of as follows: During the time the arc burns between electrode and workpiece, there is formed, under an envelope of flux, a hollow filled with gases and vapors of the metal and the flux. As the arc continues to burn, the gas pressure and the volume of the hollow may undergo a change. Now and then, the flux envelope may be broken by gases, the pressure inside the hollow falls off and the molten flux tries to fill the space between the electrode and the base metal.

At a low pressure inside the hollow, the flux may be in direct contact with the hot tip of the electrode, and the voltage between the electrode and the workpiece may drop to below the value required for formation of a shunted arc. As the current flows through the flux, the latter is locally heated to a very high temperature; this leads to an increase in the pressure within the hollow, a forcing back of the flux from the hot end of the electrode, a lowering of the conductivity of the flux, an increase in voltage in the electrode gap and, hence, to formation of an arc.

While the arc is burning, the extent to which it is shunted by the molten flux may vary within wide limits.

At the times the polarity of the current is reversed, a certain part of the space between the electrode and the pool of molten metal may remain unfilled with molten flux and in this way, become conditioned for the formation of an arc.

The flux conductivity must be assumed to be a constantly acting conductivity, analogous to the arc conductivity. While the arc is burning, the current in the electrode constitutes the total of the current passing through the arc and through the molten flux connected in parallel.

Welded Continuous Frames and Their Components

Study of the plastic behavior of continuous beams together with a discussion of the deformation of structures in the plastic range and a criterion for selection of the full load in the plastic design method

by Ching Huan Yang, Lynn S. Beedle and Bruce G. Johnston

Progress Report No. 3: Plastic Design and the Deformation of Structures

INTRODUCTION

IT HAS been shown by a number of authors that structural design by the plastic method may effect a considerable saving of materials and also be a simpler procedure than the conventional elastic method. The deformation of a continuous beam or frame designed by the plastic method is expected to be larger than that of a similar indeterminate structure designed elastically, but is usually less than that of a similar determinate structure. In this report it is shown that most of the reserve load-carrying capacity of such structures may be utilized without the danger of excessive deformation, the limitation being provided by a convenient method suggested.

If a structure designed elastically is loaded beyond its full load* a part of the structure will yield. In most cases yielding will not cause instability. After some yielding, the rotations and deflections of some indeterminate structures may still be within a limit which can be allowed in practical designs. Of course this fact has been mentioned recently by writers on "limit" or "plastic" design.[1-5]

The recent emphasis on this subject may in part be attributed to the development of welding. By this means it is possible to join members with economy and at the same time allow the transmission of the full cross-sectional strength from one member to another. Thus welding can provide a completely continuous frame (often termed a "rigid" frame) and it is sought to take advantage of such continuity through rational design methods.

Baker[5] has suggested the use of plastic design for certain practical engineering structures, and it is interesting to note that the British designer is now allowed to use the plastic method. The British Standard Specification states in part,

". . . for the purpose of such design accurate methods of structural analysis shall be employed leading to a load factor of 2.0, based on the calculated or otherwise ascertained failure load of the structure or any of its parts, and due regard shall be paid to the accompanying deformations under working loads, so that deflections and other movements are not in excess of the limits implied in this British Standard."

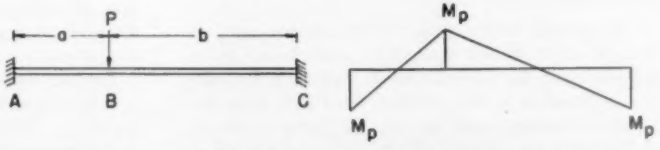
To illustrate some of the concepts of plastic behavior (and in particular that of deformation) an examination will now be made of the load-deflection relationship of an indeterminate structure "fixed" by welding to a rigid boundary.

For example, consider a beam with uniform section loaded as shown in Fig. 1 with a concentrated load closer to one support than the other.

As the load P increases the yield stress is reached first at support A. By the simple plastic theory a "plastic hinge" will be formed subsequently at A. As the load P increases, the yield stress is next reached at section B and eventually at C as shown in the diagram of moment at collapse.

When the maximum deflection of the beam is plotted against load P the curve shown in Fig. 2 results.

The curve consists of three approximately straight-line portions joined by short curves. The portion OA represents



Beam Fixed at Both Ends — Moment Diagram at Collapse

Figure 1

Ching Huan Yang, Lynn S. Beedle, are connected with the Fritz Engineering Laboratory, Department of Civil Engineering and Mechanics, Lehigh University, Bethlehem, Pa., and **Bruce G. Johnston,** formerly Director of the Laboratory, is now at the University of Michigan.

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* Full load is defined as the working load multiplied by the factor of safety.

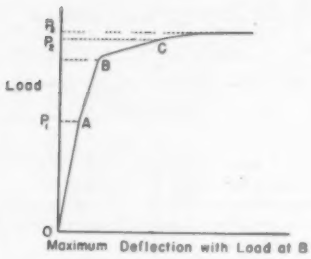

Figure 2

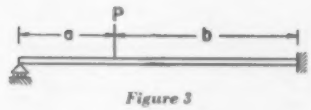

Figure 3

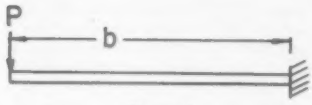

Figure 4

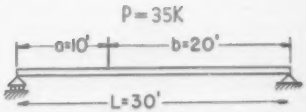

Figure 5

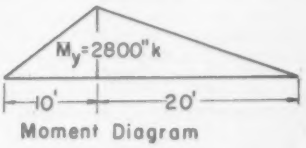

Figure 6

the load-deflection relationship when the whole structure is within the elastic range. The segment AB represents the load-deflection relationship of the beam shown in Fig. 3 loaded within the elastic range and is superimposed on segment OA which describes deflections that have already taken place (A is the origin for the sloping line AB).

Likewise the load-deflection curve of the beam shown in Fig. 4 loaded within the elastic range will be similar to the portion BC of Fig. 2 and will have its origin at B, the abscissa of which represents all of the deflection which has taken place prior to the formation of a plastic hinge at B.

According to conventional elastic design, the beam shown in Fig. 1 will only be expected to carry the load P_1 although only one part of the beam reaches the yield stress. This reveals the defect of applying the criterion of stress to this type of structure when elastically designed. The structure will hold the external and internal forces in equilibrium at a load much higher than P_1 although the deformation of the structure increases at a higher rate as the load goes higher than P_1. If the load is kept below P_2 in Fig. 2, the rate of deflection will not be any greater than that in the elastic structure shown in Fig. 4. Thus, from the viewpoint of strength of the structure, it seems reasonable that the full load should be raised to P_2 instead of restricting it to P_1 as governed by the criterion of a limiting stress.

When designing a structure, in addition to requiring that all external and internal forces be in equilibrium, the engineer usually requires that deformations be held within certain limits. Therefore, as long as the structure can hold the loads within an allowable limit of deflection, it will not matter if the flexural stress of the structure exceeds the yield point.

As a matter of fact, in many conventional bridge and building designs, engineers often find the stress-criterion unsatisfactory due to large elastic deformations which current specifications will not allow.

These considerations suggest that the design criterion of structures should be based on deformation instead of stress. (This has also been discussed by Van den Broek[1]). However, a number of basic questions are posed. If the plastic design method is used and the deformation of structures is limited, will a more economical design result? Rolled structural steel members are believed to have reduced resistance to buckling in the plastic range. Would this buckling prevent the wide application of the plastic design method? It is known that the elastic design of indeterminate structures more often than not involves a lengthy and laborious procedure. Will the procedures in plastic design be more or less complicated?

The program for investigating the plastic behavior of continuous beams, carried on at Lehigh University, has thrown further light on these questions. A discussion of the deformation of structures in the plastic range is given in this report, together with a criterion for selecting the full load in the plastic design method. Discussion of some of the remaining questions will be included in a forthcoming report on the results of continuous beam tests.

It is not the purpose of this paper to present rigorous methods for computing deflections. This is being treated separately. Attention is restricted to the first question posed above regarding a limitation of deflection.

DEFORMATION OF STRUCTURES IN THE PLASTIC RANGE

If deformation is a logical criterion for satisfactory structural design, then what limitation should be adopted? Actually, a beam made of mild steel as shown in Fig. 1 will carry additional load even after three plastic hinges are developed (at A, B and C). Any additional load will only cause direct tensile stresses in the member, assuming the supports of the beam are prevented from moving inward longitudinally. The load capacity then is limited by the deformation which can be allowed in actual practice and not by a condition of equilibrium.

In elastic design, although stress is used as a criterion, it is usually found that the deformation of the structure has been limited automatically. A simple example is found in a statically determinate structure. When the yield strength is reached, the deformation will increase very rapidly with only a small increment of additional load. In this case the criterion of stress is also a criterion of deformation in design. However in indeterminate structures one will usually find that the criterion of stress will provide an inherent deformation limitation that is often too far on the safe side. The deformations in indeterminate structures usually do not increase as rapidly as those in statically determinate structures after reaching their yield strength.

This fact is made more evident in the following example. Here the relation between stress and deflection in statically determinate and indeterminate structures is compared by designing a beam in three ways: simply supported, "fixed-ended" and, finally, provided with two plastic hinges.

In the first two examples, although the principles of elastic behavior govern the design, the procedure is somewhat different from practice. It is customary for the engineer to select beams on the basis of a permissible working stress whereas the computations that follow have left the assigning of a safety factor until the end. This was done to facilitate the comparison of deflections both at full load and at the working load.

(*a*) *Simply-supported beam designed elastically.* With the "full load" (working load multiplied by the factor of safety) and span shown in Fig. 5, it is found that the yield moment is 2800 in.-kips as shown in the moment diagram of Fig. 6.

Use $\sigma_y = 33$ kips/in.^{2}; $S = M_y/\sigma_y = 85$ in.^{3}

Use 18WF50 ($S = 89$, $I = 800.6$).

Making use of tables the maximum deflection of the beam loaded with the full load will then be

$$\delta_{max} = \frac{Pab(2a + b)\sqrt{3b(b + 2a)}}{27EIL} = 1.22 \text{ in.}$$

(*b*) *Beam fixed at both ends, designed elastically* (Fig. 7). Since the maximum moment is at A,

$$M_A = M_y = \frac{Pab^2}{L^2} = 1870 \text{ in.-kips}$$

$$S = \frac{M_y}{\sigma_y} = \frac{1870}{33} = 56.6 \text{ in.}^3$$

Use 16WF36 ($S = 56.3$, $I = 446.3$).

The maximum deflection of the beam loaded with the full load will then be

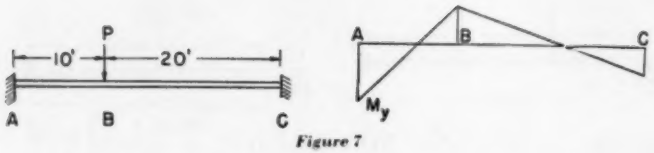

Figure 7

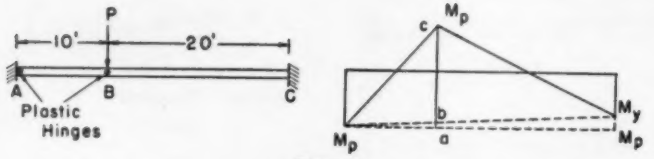

Figure 8

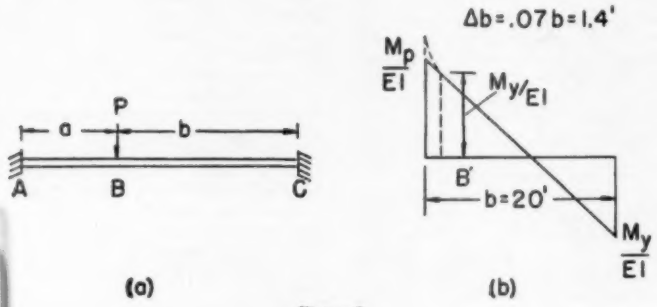

Figure 9

$$\delta_{max} = \frac{2Pb^2a^2}{3EI(3b + a)^2} = 0.49 \text{ in.}$$

Note that in case (*a*) the maximum deflection of the simply-supported beam is three times as large as the maximum deflection of the beam with fixed ends, case (*b*).

The next logical step, based on the concepts of plastic behavior, is to design the beam with plastic hinges. Figure 2 shows clearly that with the formation of three plastic hinges, corresponding to load P_3, the deflection is very large. However, at load P_2, where the formation of the last plastic hinge is just commencing (at point C), the deflection is determinate. Thus, this case is selected next.

(*c*) *Beam with plastic hinges at points A and B.* The beam is designed on the condition that plastic hinges have developed at *A* and *B* and the yield stress is just reached at *C*. According to the simple plastic theory the moment diagram for this condition is shown in Fig. 8

From the moment diagram, we have

$$bc = \frac{Pab}{L} = ac - ab$$

$$\therefore \frac{Pab}{L} = 2M_y - \frac{a}{L}(M_y - M_y) \quad (1)$$

There is available a convenient term, f, called the "shape factor," where

$$f = \frac{M_p}{M_y}$$

Thus Equation 1 becomes

$$\frac{Pab}{L} = M_y\left(2f - \frac{af}{L} + \frac{a}{L}\right)$$

and

$$M_y = \frac{Pb}{(2fL/a) + (1 - f)} \quad (2)$$

Substituting in Equation 2 the given numerical values and assuming a shape factor of 1.15,

$$M_y = 1240 \text{ in.-kips}$$

and

$$S = \frac{M}{\sigma_y} = \frac{1240}{33} = 37.5 \text{ in.}^3$$

Use 14WF30 ($S = 41.8$, $I = 289.6$)

Figure 9 (*b*) shows the M/EI diagram for length BC of the beam whose moment diagram was sketched in Fig. 8.

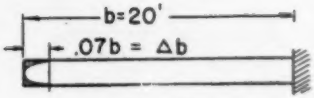

Figure 10

The region near point *B* will yield as shown in Fig. 10, and plastic strains will be experienced for the distance Δb, at the right end of which (point B') the moment is equal to M_y.

From Fig. 9 (*b*) we may calculate the length Δb of the yielded portion. Thus

$$\frac{b - \Delta b}{b} = \frac{2M_y}{M_y + M_y} = \frac{2}{1 + f}$$

$$\Delta b = b\left(1 - \frac{2}{1 + f}\right)$$

For the assumed shape factor, $f = 1.15$,

$$\Delta b = 0.07b = 1.4 \text{ ft.}$$

The slope of the elastic line is zero at point *C*, and by examination of the M/EI diagram it is apparent that the slope is also zero at point B'. (The curvature of the beam to the left of B', in the region of the plastic hinge, must be upward from the tangent at B'.) So long as the beam remains elastic at *C*, the maximum deflection will be located at B' and can be conveniently calculated by the moment-area method.

$$\delta_{max} = \frac{M_y(b - \Delta b)^2}{6EI} = \frac{2M_yb^2}{3(1 + f)^2EI} = 1.33 \text{ in. (using a 14WF30 section)}$$

The load corresponding to this deflection may be calculated and will be found to be 38.8 kips instead of 35 kips (see Appendix B). This beam has a section modulus of 41.8 in.^{3} rather than the required 37.5 in.^{3}

Comparing the three different designs (*a*), (*b*) and (*c*), we find the deformation of the third design relatively small, being only 9% greater than that of the simply-supported beam in design (*a*). Deflections under the full load have been computed in the above discussion. Since the engineer customarily computes deflections under the working load, this has also been done using a safety factor of 1.65 for the elastic designs and a load factor of 1.65 for the plastic design. The results are shown in the following table, tabulated with the full load deflections for the three different designs studied.

In case (*c*) above, to compute the deflection, under the working load, refer first

Design method	*Section used*	*Maximum possible deflection under working load, in.*	*Maximum possible deflection under full load, in.*
(*a*) Elastic design using simply-supported beam	18WF50	0.74	1.22
(*b*) Elastic design using fixed-ended beam	16WF36	0.30	0.49
(*c*) Plastic design (limiting the deflection)	14WF30	0.46	1.33
Specification limit for deflection (1/360 × span) = 1.00 in.			

to Fig. 2. With a load factor of 1.65, the working load will be very close to load P_1. As a check,

$$P_W = \frac{P_2}{\text{Load Factor}} = \frac{35}{1.65} = 21.2 \text{ kips}$$

$$M_A = \frac{Pab^2}{L^2} = 1135 \text{ in.-kips}$$

Now for the 14WF30 section

$$M_y = 1380 \text{ in.-kips}$$

Thus the beam is within the elastic range under working loads and, as in case (*b*),

$$\delta_{max} = \frac{2P_W b^2 a^2}{3EI(3b + a)^2} = 0.46 \text{ in.}$$

From the above table it is seen that by use of plastic design a 17% savings in material is possible over the fully restrained "elastic" beam, the deflection of the "plastic" beam at working loads being less than the simply-supported beam. In each case, deflections are less than the specification limit.

The example chosen (Fig. 1) was selected because its load-deflection relationship (Fig. 2) demonstrates the step-by-step formation of the three plastic hinges. However, in many engineering structures the design is based on uniformly loaded beams. Appendix A has been prepared to show the load-deflection relationships for such loading. Also the case of a single concentrated load at the center is presented. In addition, comparative deflections similar to those in the above table have been developed. The results of the deflection computations are shown in the following table.

	Uniform load			Central concentrated load		
		Maximum deflection, in.			Maximum deflection, in.	
Design method	*Section*	*Working load*	*Full load*	*Section*	*Working load*	*Full load*
(*a*) Simple beam, elastic design	18WF47	1.00	1.65	18WF55	0.77	1.27
(*b*) Fixed beam, elastic design	16WF36	0.33	0.56	16WF36	0.39	0.64
(*c*) Plastic design	14WF30	0.50	1.65	16WF36	0.39	0.64

The approximate load-deflection curves for all three designs are shown, nondimensionally, in Fig. 11.

The necessary information for plotting these load-deflection curves is to be found in Appendix B.

The following observations may be made based on Appendices A and B, Fig. 11, and the foregoing tables:

(*a*) As in the case of a beam with concentrated load off-center, a 20% saving of material may be made using plastic design when the beam is loaded uniformly. Deflections at working load are about one-half those of the simple beam.

(*b*) The same section is chosen in designing the beam for the first two loading conditions (concentrated load off-center and uniformly distributed load).

(*c*) The uniformly loaded beam has the same reserve capacity above the load at initial yield as that with load off-center.

(*d*) Considering (*b*) and (*c*) above, a portion of this condition is due to the fact that a beam is not available for every section modulus.

(*e*) For the central concentrated load, the elastic and plastic solutions give identical results.

(*f*) In each of these plastic designs, the beam is completely elastic at the working loads. It is believed that most other similar structures designed with the same load factor would also be elastic.

The considerations thus far suggest an approximate method for computing deflections which is outlined in Appendix C. Plastic zones are neglected. When compared with computations based on the simple plastic theory, the error is on the safe side, the discrepancy becoming large when the shape factor is large.

Hechtman and Johnston[6] have introduced the semirigid connection in the design of building frames indicating an economy of material. The relief of end moments by semirigid connections in a beam with fixed ends has at the same time increased the deformation of the member just as in case (*c*) where the hinge acts as a semi-rigid connection.

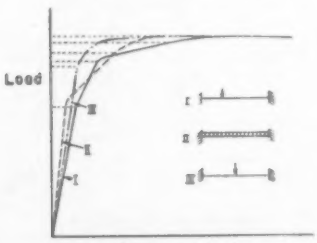

Figure 11

When floor beams carry ceilings with plaster, the maximum deflection of the beam under working load is limited by the A.I.S.C. Specifications to $L/360$ where L is the span length. From the above tables, this requirement is satisfied in all of the designs.

However, there are many structures in which such a limitation is probably not necessary since plaster is not used. In this respect, the authors are in agreement with Prof. J. F. Baker who has often expressed the need for suitable deflection limitations for such other structures.

Theoretically, it is possible to design elastically an indeterminate structure to behave like a determinate one; that is, after the yield stress is reached the deformation increases rapidly. The following two illustrations demonstrate this idea.

Neglecting the shearing force, suppose the section modulus of a beam is varied to be in proportion to its moment diagram. Then every section of the beam will reach the yield stress at the same time. Any further increase of load would cause a rather large deformation that can hardly be disregarded in general engineering structures. This design, however, is usually impractical because of fabrication difficulties, complication of design procedures and the fact that structures so designed do not satisfy other loading systems.

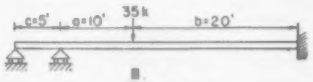

Figure 12

As a second example the beam chosen in Fig. 12 has one end elastically supported and the other end fixed-ended as before. The elastic support length c is arbitrarily chosen as 5 ft.

We find $M_y = 1690$ in.-kips by the usual methods and, assuming $\sigma_y = 33$ kips/in.,^{2} then,

$$S = \frac{1690}{33} = 51.2 \text{ in.}^3$$

This design is closer to the plastic design (*c*) than design (*b*) in which both ends were fixed-ended. The moment diagram of the above design is shown in Fig. 13. The maximum moment still occurs at A. But the moments at B and C are higher than in the case where both ends were fixed. The ideal design is to make all three sections of

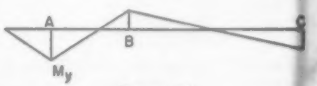

Figure 13

the beam (A, B and C) reach the yield moment at the same time. It is practically impossible in this beam. In ordinary design the change of section modulus along one member is usually avoided and the end supports can hardly be designed to suit one loading system. Indeterminate structures cannot be designed practically to behave like determinate structures, i.e., the possible plastic hinges cannot be designed to develop at the same time. Plastic design is therefore aimed to make use of the reserve strength of an indeterminate structure between the initial yield load and the load at which all possible plastic hinges develop.

PLASTIC DESIGN BASED ON A LIMITATION OF DEFLECTION

On seeking a practical means of plastic

design by limiting the deformation of structures the example of Fig. 1 may be examined. The final design, case (*c*), has a good limitation of maximum deflection in the plastic range, namely, the load P_3. In such comparatively simple indeterminate structures it is possible to design by investigating the whole sequence of elastic and plastic behavior of the structure until enough plastic hinges develop to make the indeterminate structure act as a determinate one as shown in Fig. 8. Then we design this "plastic determinate" structure on the basis of the initial yield strength of the last hinge.

The difficulty of using this criterion for limiting the deflection would arise from the complication of the design method when the redundancy of the structure increases. It would be necessary to go into a detailed investigation of the elastic-plastic behavior of the structure under gradually increasing loads. This involves a long and laborious procedure in highly redundant structures.

Neglecting the problem of deflection for the moment, the ultimate strength of an indeterminate structure can be obtained by a direct method, discussed in

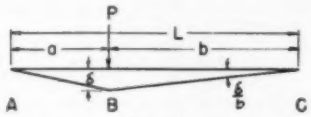

Figure 14

Greenberg's recent paper.[7] For the previous example the procedure is as follows. Put plastic hinges at *A*, *B* and *C* (Fig. 14) and apply a virtual displacement at point *B*. The virtual work done by force *P* is:

$$W = P \times \delta$$

The work done by the plastic hinges in each case equals the angle of rotation multiplied by the corresponding moment.

$$(M_p)_A \times \frac{\delta}{a} + (M_p)_B \times \frac{\delta}{a} + (M_p)_B \times \frac{\delta}{b} + (M_p)_C \times \frac{\delta}{b} = W = P\delta \qquad (3)$$

$$M_p = \frac{PL}{9} = 1400 \text{ in.-kips}$$

Assume

$$\sigma_y = 33 \text{ kips/in.}^2$$
$$M_p = \sigma_y Z$$
$$Z = 42.5 \text{ in.}^3$$

where Z = static moment of the section about the neutral axis.

Assuming $f = 1.15$, then $S = 37.0$ in.^{3}

The value of section modulus is even less than design (*c*) (which has $S = 37.5$). The design is more economical (although the same section, 14WF30, would be required). But upon examination of the load-deflection curve (Fig. 15) we find that the deflection corresponding to the load P_3 is infinite.

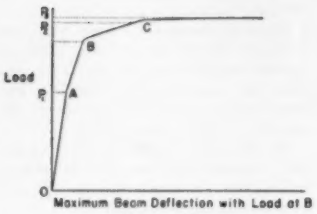

Figure 15

It is the load P_3 that is recommended as the "full load" of the structure and is selected to limit the deformation. However, only P_2 can be found by the direct method of virtual work.

Suppose we divide the load P_3 by the shape factor of the member and call the new load P_4:

$$P_4 = \frac{P_3}{f}$$

The same result would be obtained if we replaced all the M_p values in the structure by M_y. By the principle of virtual work we have

$$\delta P_3 = \alpha_A M_p + \alpha_B M_p + \alpha_C M_p$$

or

$$P_3 = \frac{\alpha_A}{\delta} M_p + \frac{\alpha_B}{\delta} M_p + \frac{\alpha_C}{\delta} M_p$$

and

$$P_4 = \frac{\alpha_A}{\delta} M_y + \frac{\alpha_B}{\delta} M_y + \frac{\alpha_C}{\delta} M_y \quad (4)$$

where the α's are the angular displacements at each point.

The moment distributions at loads P_3 and P_1 are shown in Fig. 16.

Using the principle of virtual work and noting that M_B and M_C are less than M_y in Fig. 16 (*b*), we have

$$P_1 = \frac{\alpha_A}{\delta} M_y + \frac{\alpha_B}{\delta} M_B + \frac{\alpha_C}{\delta} M_C$$

$$P_2 = \frac{\alpha_A}{\delta} M_p + \frac{\alpha_B}{\delta} M_p + \frac{\alpha_C}{\delta} M_y$$

Since the geometric dimensions are fixed, the terms α, s/δ are constant. Comparing the above expressions with Equation 4 the following result is obtained

$$P_1 \leq P_4 \leq P_2$$

The shape factor of an "I" section lies between 1.1 and 1.22. Therefore P_4 is usually very close to P_3.

Let us redesign the beam by this modified procedure. Using the virtual work method, Expression 3 becomes

$$(M_p) \times \frac{\delta}{a} + (M_p) \times \frac{\delta}{a} + (M_p) \times \frac{\delta}{b} + (M_p) \times \frac{\delta}{b} = P \times f \times \delta \quad (5)$$

$$M_p = \frac{PfL}{9} = M_y f$$

Therefore

$$M_y = \frac{PL}{9} = 1400 \text{ in.-kips}$$

$$S = \frac{M_y}{\sigma_y} = 42.5 \text{ in.}^3$$

The section modulus selected in this design is only slightly higher than the one found in design (*c*) in which we assumed plastic hinges at sections *A* and *B* and the yield moment, M_y, at section *C* of the beam. The deflection of design (*c*) was less than that of a simply supported beam designed within the elastic limit, and since S in this new design is slightly higher, its deformation will be further reduced.

Therefore load P_4 is suggested as the full load in case the redundancy of the structure is comparatively high. The load P_4 can be determined without a knowledge of the shape factor since the hinge value is reduced from M_p to M_y. Thus Expression 5 could be written in simpler terms

$$M_y \frac{\delta}{a} + M_y \frac{\delta}{a} + M_y \frac{\delta}{b} + M_y \frac{\delta}{b} = P\delta \quad (6)$$

Of course, the load P_3 may be assumed as the full load in the comparatively simple structures used as examples in this paper.

This design method will give the same result as an elastic design whenever an efficient elastic design can be achieved. One of the examples of Appendix A is an illustration of this, shown in Fig. 17. By the suggested plastic design method, with plastic hinges at *A*, *B* and *C*,

$$P = \frac{M_y}{L/2} + 2\frac{M_y}{L/2} + \frac{M_y}{L/2} = 8\frac{M_y}{L}$$

$$S = \frac{PL}{8\sigma_y} = 47.8 \text{ in.}^3$$

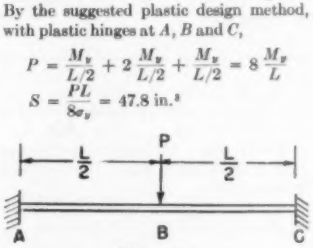

Figure 17

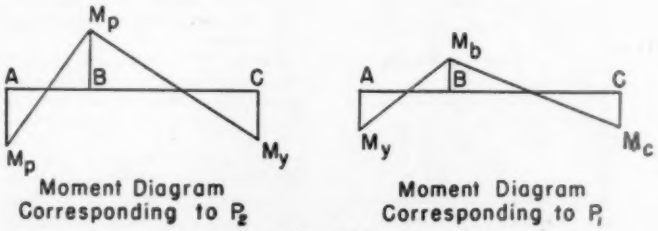

Figure 16

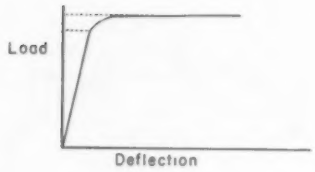

Figure 18

The identical result is obtained in elastic design. The load deflection curve of this beam is shown in Fig. 18.

The deflection curve of this beam has only one straight line part although it is an indeterminate structure. We have shown that the design load P_4 is between P_2 and P_1 in the previous example. In this case, however, P_2 and P_1 approach one point,

$$P_2 = P_4 = P_1$$

DISCUSSION

Continuous Frames

In this report beams are used as examples for the sake of simplicity. In many rigid frames the effects of axial load are negligible and the problem is basically the same as that of continuous beams. Therefore the principles discussed herein will equally apply to the design of such frames.

Full Load and Working Load

A structure designed to take a certain load may fail before reaching that load due to unavoidable errors that may be introduced in the design. Hardesty[9] has discussed this from an allowable stress point of view. Marin[10] has also tabulated possible sources of error in design. Such discrepancies are:

(*a*) overrun in computed dead loads,
(*b*) future increase in live loads,
(*c*) loss of section due to corrosion,
(*d*) approximations in stress analysis,
(*e*) underrun in dimensions and physical properties,
(*f*) inadequate design theory,
(*g*) errors in distribution of load,
(*h*) errors in fabrication and erection,
(*i*) time effects.

Therefore, in actual design, engineers are accustomed to design on the basis of a working load determined by dividing the full load by a certain factor to cover these possible errors. The multiplying factor is called the "Factor of Safety" and its value may be determined by the magnitude of possible errors, estimated statistically.

It is obvious that the chance for all these possible errors to be present simultaneously is small. But the use of the "Factor of Safety" in design does not eliminate all possibility for the structure to reach the full load stresses and deformations. It has only reduced this probability to a certain extent.

Usually in checking the deflection of a structure, no matter what design method is used, it is customary to use the working load. However, the statistical nature of the factor of safety (or load factor) makes it desirable to keep the deflections within some reasonable limit at the full load, and the method recommended provides this limit.

SUMMARY

1. In plastic design the criterion of strength of continuous beams and frames should be based upon a limit of deformation rather than upon the ultimate collapse load.

2. According to the criterion of deformation, such indeterminate steel structures may have considerable reserve carrying capacity beyond the flexural yield point, whereas for determinate structures this reserve strength is very small.

3. The amount of reserve capacity depends on the structure and the loading.

4. A large portion of this reserve capacity may be used in design without the danger of excessive deformations by a direct method of plastic design assuming that the "hinge value" is M_y instead of M_p as given by the simple plastic theory.

5. For relatively simple structures, further improvement over Item 4 above is accomplished by using as the full load that at which the formation of the last hinge is just commencing (the full load = P_2 as given in the text).

6. The deflections of continuous beam spans under working loads are usually less than those of simply-supported beams designed elastically.

7. A structure so designed will usually be loaded within the elastic limit in the range of its working load.

8. An approximate method for computing deflections is suggested in Appendix C.

ACKNOWLEDGMENTS

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Appendix A

LOAD-DEFLECTION RELATIONS FOR A UNIFORMLY-LOADED BEAM AND A BEAM WITH CONCENTRATED LOAD

In addition to the example shown in the text, two other conditions are examined as shown in Fig. 19.

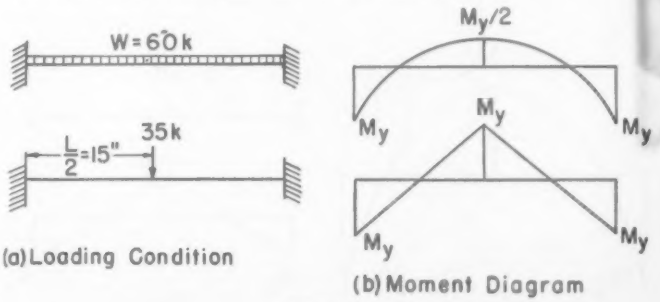

Figure 19

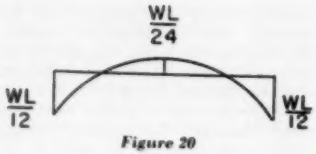

Figure 20

BEAM WITH UNIFORM LOAD

In the design of the uniformly-loaded beam, comparison is made with the same three design conditions selected in the text. The load of 2^k/ft. is selected since it gives about the same maximum bending moment as case (*a*) of the previous example.

(*a*) *Simple beam designed elastically.*

$$M_y = M_L = \frac{WL}{8} = 2700 \text{ in.-kips}$$

$$S = \frac{M_y}{\sigma_t} = 82.0 \text{ in.}^3$$

Use 18WF47 ($S = 82.3, I = 736.4$).

$$\delta_{max.} = \frac{5WL^3}{384EI} = 1.65 \text{ in.}$$

(*b*) *Fixed-ended beam, designed elastically. (Fig. 20)*

$$M_y = \frac{WL}{12} = 1800 \text{ in.-kips}$$

$$S = 54.5 \text{ in.}^3$$

Use 16WF36 ($S = 56.3, I = 446.3$).

$$\delta_{max.} = \frac{WL^3}{384EI} = 0.555 \text{ in.}$$

(*c*) *Fixed-ended beam, designed plastically.*

Selecting the load "P_2," as the full load as before (Fig. 2) and using the moment diagram of Fig. 21.

$$\frac{WL}{8} = M_y + fM_y = (1 + f)M_y$$

$$M_y = (WL/8)/(1 + f)$$

$$= 1260 \text{ in.-kips.}$$

$$S = 38.2 \text{ in.}^3$$

Use 14WF30 ($S = 41.8, I = 289.6$).

Neglecting, again, the plastic zone in the beam the deflections are computed by moment areas. (Assume $M_y = \sigma_y S$ $33 \times 41.8 = 1380$ in.-kips.)

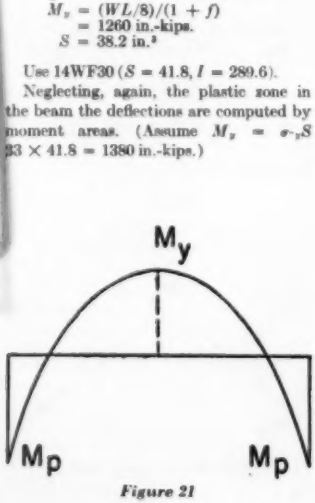

Figure 21

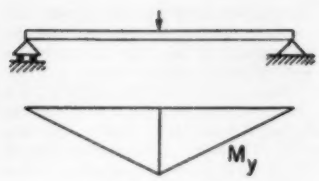

Figure 22

$$EI\delta_{max.} = \int\int_A^B M\,dxdx =$$

$$\frac{2}{3}(M_y + M_y f)\frac{L}{2}\left(\frac{5}{16}L\right) - M_y f \frac{L}{2} \times \frac{L}{4}$$

DEFLECTION AT WORKING LOADS

$$\delta(a) = \frac{1.65}{1.65} = 1.00 \text{ in.}$$

$$\delta(b) = \frac{0.55}{1.65} = 0.33 \text{ in.}$$

$\delta(c)$: Checking the moment when the load $= \frac{60}{1.65} = 35.4$ kips, this value is less than P_y, thus the beam is entirely elastic, and

$$\delta(c) = \frac{WL^3}{384EI} = 0.50 \text{ in.}$$

BEAM WITH CENTRAL CONCENTRATED LOAD

(*a*) *Simple beam designed elastically* ($P = 35^k$). (Fig. 22)

$$M_y = \frac{PL}{4} = 3150 \text{ in.-kips}$$

$$S = 95.5 \text{ in.}^3$$

Use 18WF55 ($S = 98.2, I = 889.9$).

$$\delta_{max.} = \frac{PL^3}{48EI} = 1.272 \text{ in.}$$

(*b*) *Fixed-ended beam (elastic design). (Fig. 23)*

$$M_y = \frac{PL}{8} = 1575 \text{ in.-kips}$$

$$S = 47.8 \text{ in.}^3$$

Use 16WF36 ($S = 56.3, I = 446.3$).

$$\delta_{max.} = \frac{PL^3}{192EI} = 0.636 \text{ in.}$$

(*c*) *Fixed-ended beam (plastic design). (Fig. 24)*

In this case $P_3 = P_1$ and the solution is identical with (*b*) above:

Use 16WF36.

$$\delta_{max.} = 0.636 \text{ in.}$$

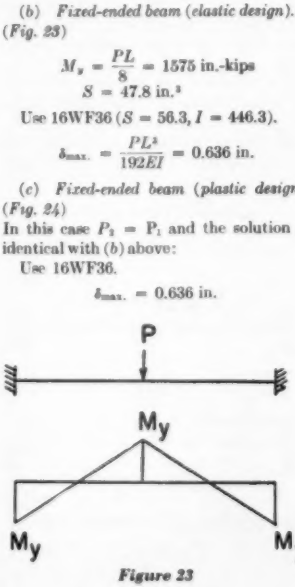

Figure 23

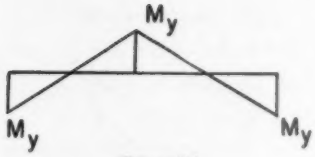

Figure 24

Appendix B

LOAD-DEFLECTION RELATIONS FOR BEAMS UNDER VARIOUS LOAD CONDITIONS

This appendix contains the information necessary for plotting the load-deflection curves of Fig. 11.

The example of Fig. 2 is repeated in Fig. 25. This curve is computed as follows:

$$P_1 = M_y L^3/ab^2 \qquad (a)$$

P_2 is determined from the load and moment diagrams shown in Fig. 26 using superposition. Again the short curved portions of the M/EI diagram are neglected. The angle changes at C, due to the separate loadings (*d*), (*e*), and (*f*), are obtained by the conjugate beam method.

$$EI\alpha_d = \frac{M_e}{6}(2a + b)$$

$$EI\alpha_e = \frac{M_e L}{3}$$

$$EI\alpha_f = \frac{M_p L}{6}$$

But

$$\alpha_d + \alpha_e + \alpha_f = 0$$

and

$$M_p = fM_y$$

$$\therefore M_e = \frac{M_e}{2L}(2a + b) - \frac{M_y f}{2}$$

Adding moments under the load in (*d*), (*e*) and (*f*),

$$M_e - \frac{bf}{L}M_y - \frac{a}{L}M_e = M_y$$

From the above two equations,

$$M_e = M_y \frac{(L + bf)(2a + b) - fL^2}{2L^2 - a(2a + b)}$$

Now,

$$M_e = P_2 \frac{ab}{L}$$

Substituting in the second of the two simultaneous equations,

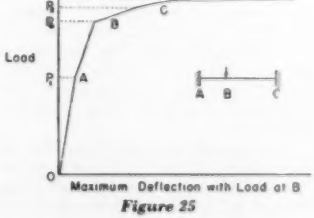

Figure 25

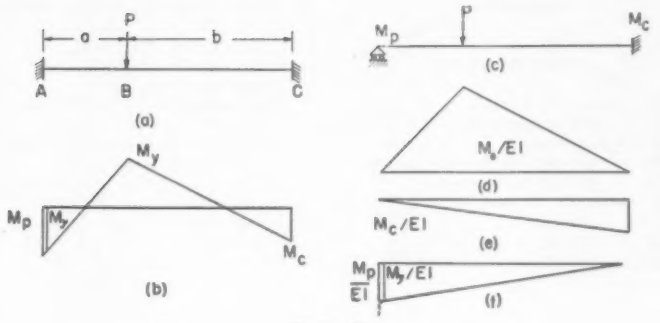

Figure 26

$$P_o = M_y \frac{L}{ab} \times \left[1 + \frac{bf}{L} + \frac{a}{L}\left(\frac{(L + bf)(2a + b) - fL^2}{2L^2 - a(2a + b)}\right)\right] \quad (b)$$

P_2 is determined from Eq. (2),

$$P_2 = \frac{M_y}{b}\left(\frac{2fL}{a} + (1 - f)\right) \quad (c)$$

P_1, the collapse load, is computed from the moment diagram at collapse,

$$P_1 \frac{ab}{L} = 2M_y = 2fM_y$$

$$P_1 = \frac{L}{ab}(2fM_y) \quad (d)$$

Next, the slopes of the various straight-line portions are determined making use of tables such as those in the A.I.S.C. manual. For the length OA in Fig. 25,

$$\text{Slope} = \frac{P}{\delta}\Big|(OA) = \frac{3EI(3b + a)^2}{2b^3a^2} \quad (e)$$

For the length AB,

$$\text{Slope} = \frac{P}{\delta}\Big|(AB) = \frac{3EI(3L^2 - a^2)^2}{a(L^2 - a^2)^2} \quad (f)$$

and for the length BC,

$$\text{Slope} = \frac{P}{\delta}\Big|(BC) = \frac{3EI}{b^3} \quad (g)$$

Substituting in expressions (a) through (g) with the values $L = 30$ ft., $a = 10$ ft., $b = 20$ ft., $M_y = 1380$ in.-kips and $f = 1.15$, we obtain,

$$P_1 = 25.9 \text{ kips} = 0.65P_2$$
$$P_o = 35.0 \text{ kips} = 0.88P_2$$
$$P_2 = 38.8 \text{ kips} = 0.97P_2$$
$$P_3 = 39.8 \text{ kips} = 1.00P_2$$

$$\frac{P}{\delta}\Big|(OA) = 46.2 \text{ kips/in.}$$
$$\frac{P}{\delta}\Big|(AB) = 19.9 \text{ kips/in.}$$
$$\frac{P}{\delta}\Big|(BC) = 1.9 \text{ kips/in.}$$

The curve is plotted in Fig. 11.

The load-deflection curve for the uniformly loaded beam is computed in the same fashion as the previous example and is sketched in Fig. 27.

$$W_1 = \frac{12M_y}{L} = 46 \text{ kips} = 0.65W_2$$

$$W_2 = \frac{8M_y(1 + f)}{L} = 66 \text{ kips} = 0.93W_2$$

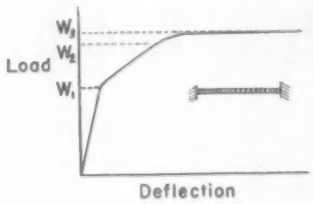

Figure 27

$$W_2 = \frac{16fM_y}{L} = 70.5 \text{ kips} = 1.00W_2$$

The two slopes are determined to be

$$\frac{W}{\delta}\Big|(OA) = \frac{384EI}{L^3} = 71.5 \text{ kips/in.}$$
$$\frac{W}{\delta}\Big|(AB) = \frac{384EI}{5L^3} = 14.3 \text{ kips/ in.}$$

The load-deflection relation for the beam with central concentrated load is sketched in Fig. 28.

$$M_y = \sigma_y S = 1860 \text{ in.-kips.}$$
$$P_1 = 8M_y/L = 41.3 \text{ kips} = 0.87P_2$$
$$P_2 = P_1$$
$$P_3 = P_1 f = 47.5 \text{ kips} = 1.00P_2$$

The slope of the elastic straight-line portion is

$$\frac{P}{\delta}\Big|(OA) = \frac{192EI}{L^3} = 55.1 \text{ kips/in.}$$

This information is plotted in Fig. 11.

In each case the short curved portions of the load-deflection plots have been sketched as an approximation.

Figure 28

Appendix C

APPROXIMATE METHODS FOR COMPUTING DEFLECTIONS

As an example we shall use the beam shown in Fig. 1. The procedure is indicated in Fig. 29. Instead of attempting to deal with the curved portions, the straight-line portions are used as shown dotted. The dot-dash relation is the result of assumptions made in previous computations when we neglected the dotted portion of the M/EI diagram (Fig. 9 (b)).

The steps are as follows:

1. Compute the loads P_1, P_o and P_2, making use of bending moment diagrams and the formulas given in the A.I.S.C. beam tables. From Appendix B expressions (a) through (c)

$$\left.\begin{aligned} P_1 &= \frac{M_o L^2}{ab^2} \\ P_o &= \frac{M_o L}{ab}\left[1 + \frac{bf}{L} + \frac{a}{L}\left(\frac{(L + bf)(2a + b) - fL^2}{2L^2 - a(2a + b)}\right)\right] \\ P_2 &= \frac{M_o}{b}\left[\frac{2fL}{a} + (1 - f)\right] \end{aligned}\right\} M_o = M_y$$

2. Compute the deflection at load P_1:

$$\delta_A = \frac{2Pb^3a^3}{3EI(3b + a)^2}$$

3. Determine the slopes AB and BC from tables.

$$\frac{P}{\delta}\Big|(AB) = \frac{3EI(3L^2 - a^2)^2}{a(L^2 - a^2)^2}$$
$$\frac{P}{\delta}\Big|(BC) = \frac{3EI}{b^3}$$

4. The deflections at points B and C in Fig. 29 may then be determined.

$$\delta_B = \delta_A + (P_o - P_1) \times \frac{a(L^2 - a^2)^2}{3EI(3L^2 - a^2)^2} \quad (h)$$

$$\delta_C = \delta_B + (P_2 - P_o) \times \frac{b^3}{3EI} \quad (i)$$

Usually the working load will be below P_1. However, should it be greater, say in the range AB, then expression (h) may be used, replacing P_o by the working load.

Although it appears from Fig. 29 that a better approximation might be

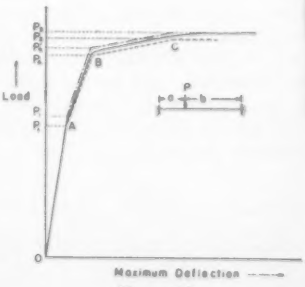

Figure 29

made by assuming $M_c = \frac{M_y + M_p}{2}$, such a recommendation is not made at the present time.

However, it appears from the discussion that beam tables could be expanded to include the above formulas, should the concepts of plastic design and analysis become common among structural engineers.

Appendix D

NOMENCLATURE

a, b = segments of length.
E = modulus of elasticity.
f = shape factor.
I = moment of inertia of a beam section about its neutral axis.
L = length of span between beam supports.
M = moment at a beam section.
M_y = yield moment at a beam section.
M_p = plastic hinge moment at a beam section.
P = applied concentrated load.
P_w = working load on beams.
S = section modulus.
W = applied uniformly-distributed load (total).
Z = static moment of area of a beam section about its neutral axis (also known as the Plastic Modulus).
α = angle change.
δ = deflection.
σ_y = yield point stress.

Relative Strain Aging Tendency of Weld and Base Metal

A discussion of the complex relationships between prestraining, strain aging and testing temperature

Discussion by E. J. Ripling and L. J. Klingler

The authors have strained steel specimens various amounts at one temperature followed by a second strain to fracture at some lower temperature. The test data were then analyzed by assuming that the sum of the first and second strains would, if no strain aging were taking place, be equal to the fracture strain of the steel when tested solely at the low temperature. Actually the evaluation of test data obtained on specimens subjected to the straining cycle described above is not this simple. In a recent series of publications it was shown that when a metal is strained at one temperature and then tested at some lower temperature, the shape of the resulting prestrain vs. retained ductility curves varied enormously depending on the material and the two strain temperatures.[1, 2] In the very simplest case when a metal is prestrained and tested so that both the prestraining and testing temperatures are above the transition temperature, the relationship between the prestrain and retained ductility is such that these can be related through the equation:

$$\left(\frac{\epsilon_p}{\epsilon_A}\right)^m + \left(\frac{\epsilon_r}{\epsilon_B}\right)^n = 1$$

where:
ϵ_r = retained ductility in the second straining operation.
ϵ_A = fracture ductility at the temperature of first strain.
ϵ_B = fracture ductility at the temperature of second strain.
ϵ_p = prestrain.

For a number of materials it has been shown that the exponents $m = n = 1$ so that the equation describes a straight line connecting a point on the ordinate representing the low-temperature ductility with a point on the abscissa representing the higher-temperature ductility as shown in Fig. 11 for S.A.E. 1340 quenched and then tempered at 1100° F. This behavior is obviously in disagreement with the "curve expected in absence of aging" used by the authors since their proposed ductility drops at such a rate as to indicate that the high- and low-temperature straining are equally harmful. (The curve shown in Fig. 11, on the other hand, indicates that straining a material at any temperature decreases its ductility in proportion to its fracture ductility at the straining temperature.) The curve suggested by the authors would result only if the ductility-testing temperature curves for the material were horizontal over the temperature range between the prestraining and testing temperature. The room temperature fracture ductility of the material represented by the 0.080- and 0.120-in. notch depths are shown for zero prestrain in Figs. 9 and 10, respectively. Using these values for

E. J. Ripling and L. J. Klingler are with the Metals Research Lab., Case Institute of Technology, Cleveland, Ohio.

Paper by R. W. Fountain and R. D. Stout was published in the *Welding Research Supplement*, January 1951.

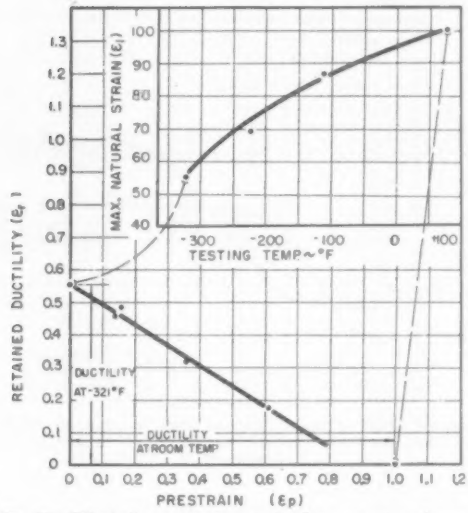

Fig. 11 Effect of prestraining at a high temperature (room temperature) on the ductility retained at a low temperature (−321°) for a material which does not show a transition temperature between the prestraining and testing temperature (S.A.E. 1340 quenched and tempered at 1100° F.)

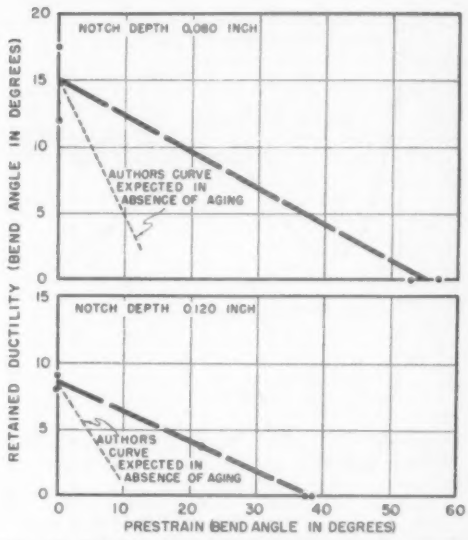
NOTCH DEPTH 0.080 INCH
AUTHORS CURVE EXPECTED IN ABSENCE OF AGING
NOTCH DEPTH 0.120 INCH
AUTHORS CURVE EXPECTED IN ABSENCE OF AGING
RETAINED DUCTILITY (BEND ANGLE IN DEGREES)
PRESTRAIN (BEND ANGLE IN DEGREES)

Fig. 12 Possible retained ductility-prestrain curves. Dotted curve suggested by the authors indicating that straining is equally harmful at the high (+70° F.) and low temperature (−70° F.), dashed curve suggesting that the damage done in straining is proportional to the ductility at the straining temperature

the abscissa intercepts and the ordinate intercepts shown in Figs. 3 and 6 would result in "curves expected in absence of aging" of the type shown in Fig. 12.

When the prestraining and testing conditions are such that the transition temperature lies between the prestrain and testing temperatures, the retained ductility-prestrain curve becomes more complex than the curve described above, as shown in Fig. 13 for S.A.E. 1340 tempered at 600° F. Here again the curve has intercepts on the ordinate represented by the low-temperature ductility and on the abscissa by the room-temperature ductility. This more complex curve decreases with small amounts of prestrain, and then increases with further prestrain to pass through a maximum and subsequently decreases to a retained ductility of zero only when the ductility is completely exhausted in prestraining. If in Fig. 13 test data were available only over the prestrain interval between (*a*) and (*b*), this curve would take on the shape of the authors' curves shown in Figs. 3, 5 and 6.

It seems probable that this more complex condition of prestraining and testing is the type exhibited by the steel in this investigation. Consequently, if larger values of prestrain were used in the test series shown in Figs. 3 and 6, the retained ductility-prestrain curves would probably exhibit a minimum and maximum as shown in Fig. 14. As a matter of fact, after a 12° prestrain, the material represented by a notch depth of 0.120 in. is beginning to show a ductility recovery. One would expect this material to recover at a smaller strain than would the material represented by the 0.080-in. notch since the testing temperature (−70° F.) is not as far removed from the transition temperature for the material at a depth of 0.120 in. as it is for that at 0.080 in. from the surface.[3] If the authors' curves, Figs. 3,

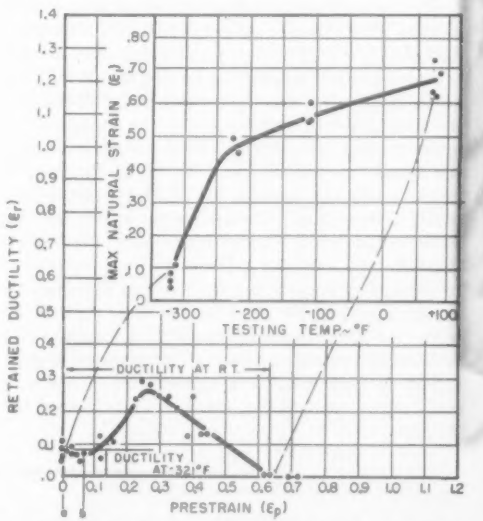

Fig. 13 Effect of prestraining at a high temperature (room temperature) on the ductility retained at a low temperature (−321°) for a material which exhibits a transition temperature between the prestraining temperature and testing temperature (S.A.E. 1340 quenched and tempered at 600° F.)

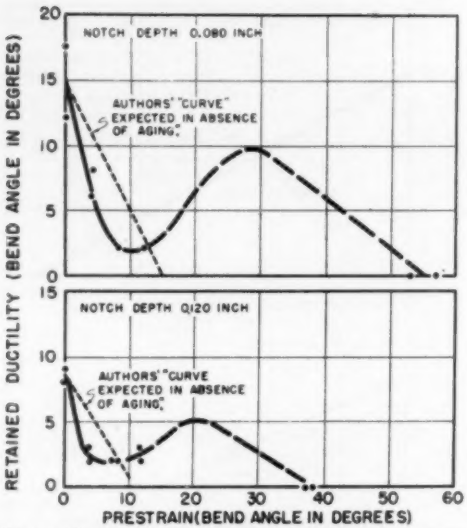
NOTCH DEPTH 0.080 INCH
AUTHORS' "CURVE" EXPECTED IN ABSENCE OF AGING.
NOTCH DEPTH 0.120 INCH
AUTHORS' "CURVE" EXPECTED IN ABSENCE OF AGING.
RETAINED DUCTILITY (BEND ANGLE IN DEGREES)
PRESTRAIN(BEND ANGLE IN DEGREES)

Fig. 14 Shape of the retained ductility-prestrained curves expected when the transition temperature lies between the prestrain and test temperature. Notice that the bows in the authors' experimental curves now become dependent on the rate of ductility recovery

5 and 6, actually have the shape shown in Fig. 14 ,then the difference between their experimental curves and their "curves expected in absence of aging" does not depend solely on strain aging but is tied in with the problem of ductility recovery such as that exhibited in Fig. 13.

The discussers would like to raise a second point. That is, if the data for zero prestrain from the authors' Figs. 7, 9 and 10 are plotted as a function of temperature as shown in Fig. 15, it can be seen that the 0.120-in. notch (which had the weld metal and coarse-grained structure removed) exhibited a lower transition temperature than the standard 0.080-in. notch, although the actual curve is lowered. However, the two data points which are available at 0° F. for the 0.160-in. notch indicate that a transition curve through these points might fall at a higher temperature than that for the standard specimen. These data are complicated by the change in notch depth; however, it appears that the specimen with the notch located in the region heated below the critical exhibits the highest transition temperature of any region tested. The presence of such a region of high transition temperature beneath the notch of the standard specimen would be expected to be

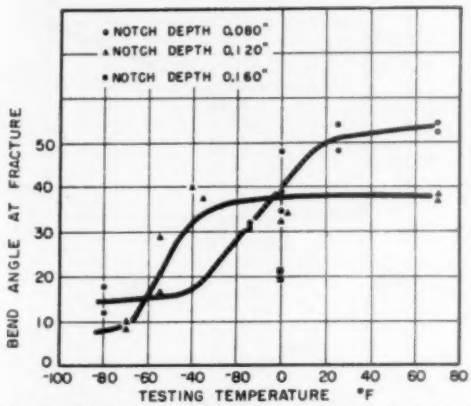

Fig. 15 Effect of temperature on ductility of single bead on plate specimens having various notch depths (zero prestrain)

an important contributing factor in the ultimate failure of the specimen.

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Authors' Reply

The authors appreciate the comments of Messrs. Ripling and Klingler.

The plot of "ductility expected in absence of aging" was kept deliberately parallel to that used by Flanigan. It is quite true that mild steel will exhibit reduced ductility—rheotropic embrittlement—at low temperatures in the absence of prestrain. The principal purpose of this brief paper was to point out that the base metal may contribute to the aging effect ascribed by Flanigan to weld metal alone.

The limited work at Lehigh has not yet demonstrated any effect of the subcritical zone on the transition temperature of longitudinal bead bend specimens. Voldrich and co-workers at Battelle Memorial Institute have also reported negative results in data soon to be published. It may be that the particular steels and welding conditions chosen may be responsible for these results.

Connections for Welded Continuous Portal Frames

Progress Report No. 4: Part I*

Investigation of portal-type structure with various types of corner connections. Results of strength, yield and stiffness of several types of corner connections are indicated

by A. A. Topractsoglou, Lynn S. Beedle and Bruce G. Johnston

I. INTRODUCTION

THE introduction of welding into the building construction field has made possible the fabrication of continuous (or "rigid") frames with economy. This, in fact, is one of the unique advantages of welding, facilitating the uninterrupted transmission of moments and shears from member to member with a minimum of extra connecting material.

A few of the many types of continuous frames are shown in Fig. 1. In this paper attention is directed to Fig. 1 (*a*), indicating a type of structure often referred to as a portal frame, the members consisting of rolled structural steel shapes.

A recent paper[1] on the elastic design of such frames has been issued by the American Institute of Steel Construction. The theory is applicable to both welded and riveted construction.

Although there are other advantages of the continuous frame such as ease of erection and pleasing appearance, of primary interest is the saving in material resulting from decrease in maximum bending moments as compared with those in a structure designed on the basis of simple supports at the beam ends.

In the work of such investigators as Prof. J. F. Baker in England and Prof. J. A. Van den Broek in this country, there has recently been demonstrated the possibility of further economies by virtue of plastic or "limit" design methods.[2-6] These economies result from (*a*) the reserve strength of rolled structural steel members in the plastic range, and (*b*) the reserve strength of fully continuous frames in the plastic range. In comparison with continuous structures designed by

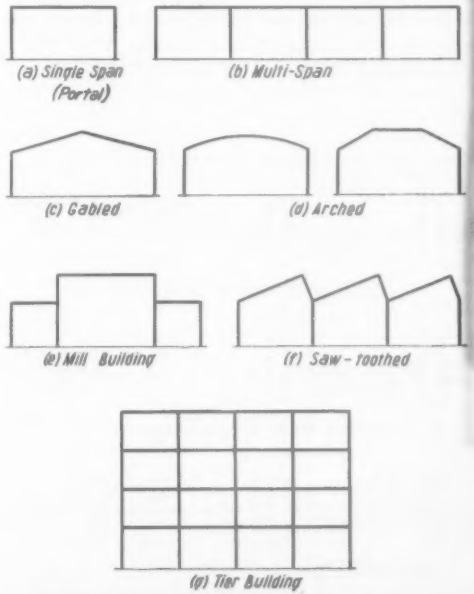

Fig. 1 Types of continuous frames

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This paper was presented before the Thirty-First Annual Meeting, AMERICAN WELDING SOCIETY, Chicago, Ill., week of Oct. 22, 1950.

* Parts II and III are to appear in successive issues of the *Welding Research Supplement*. This work has been carried out as a part of an investigation sponsored jointly by the Welding Research Council and the Department of the Navy with funds furnished by the following: American Institute of Steel Construction, American Iron and Steel Institute, Column Research Council (Advisory), Institute of Research, Lehigh University, Office of Naval Research (Contract No. 39303), Bureau of Ships and the Bureau of Yards and Docks.

elastic methods there is indicated a further economy in design costs due to the simplicity of plastic design methods.

Continuity is entirely dependent upon the connection. Unless properly designed, the connection will not fully transmit bending moments and shears from one member to adjacent ones. Thus, in order to make the components of a frame act together as an integral structure, the members must be rigidly joined by connections.

This importance of connections resulted in early attention to it in the project "Welded Continuous Frames and Their Components" being carried out at Lehigh University in the Fritz Engineering Laboratory of the Department of Civil Engineering and Mechanics.† The investigation is sponsored jointly by the Welding Research Council and the Department of the Navy with financial support by the American Institute of Steel Construction, American Iron and Steel Institute, Bureau of Ships, Bureau of Yards and Docks and the Office of Naval Research.

The design of a portal frame requires the selection of a connection, and to predict frame behavior in the plastic range it is necessary to know the load-carrying capacity of connections beyond the elastic limit.

Because of past research, it was hoped that a large number of joint tests would not be necessary. However, a majority of previous research has been done on flexible and semirigid connections (Fig. 2). Where continuous connections have been tested, very little information has been reported on their behavior beyond the elastic limit and up to collapse. Further, the recent advent of welding into the rigid-frame field has not given opportunity to develop a background of experience. Due to the difficulty in evaluating the rigidity or the strength of connections, additional stiffening undoubtedly has been provided resulting in "overdesigned" structures.

Most of the information on connection tests has been collected from work done in the United States and England. In this country a considerable number of tests have been carried out at Lehigh University on flexible and semirigid types of beam-to-column connections as used in tier-building construction[2-14] A review of research in these two countries recently has been prepared by Frankl.[15] A series of tests (unpublished) by Braithwaite and Co. in England[16] were completed on various types of welded continuous connections. The results of research by Hendry in England have recently appeared.[17]

The present series of connection tests was planned with the help of the sponsors and the Lehigh Project Subcommittee of Welding Research Council.‡

The scope was limited to a study of corner connections in portal frames, these being the simplest type, commonly called "knees" and shown in Fig. 3 (*b*). The scope of the project was further limited to a study of structures under static load.

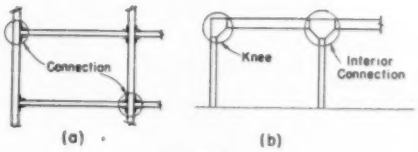


Figure 3

The specific objective was to determine the behavior of welded knees including the following aspects:

(*a*) Elastic stress distribution.
(*b*) Elastic strength of connections.
(*c*) Stiffness of connections in the elastic and plastic range.
(*d*) Ultimate strength and plastic load-deformation characteristics at or near the maximum load.
(*e*) Economy of fabrication.
(*f*) Influence of fabrication details on behavior.

It was considered that such information would be of value in the design of new structures and in describing the true load factors on existing structures.

The principal types of knees are shown in Fig. 4. Others may vary in minor detail from those shown. These have been used in existing structures, were suggested by authorities in the field or have been the subject of other research.§ Beams are shown in the horizontal position whereas in practice a large number may slope as in gabled-roof frames. As will be seen,

† A portion of the research on beams and columns has been described in three other reports.[5-7]

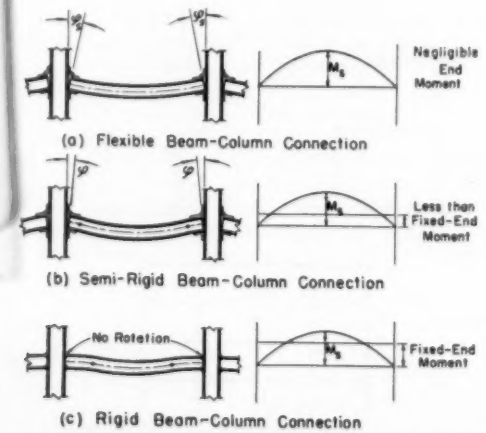


Fig. 2 Classifications of welded beam-to-column connections (from Johnston and Deits[15])

‡ Members of this Subcommittee are: T. R. Higgins, *Chairman*, A. Amirikian, Lynn S. Beedle, H. C. Boardman, J. M. Crowley, S. Epstein, F. H. Frankland, La Motte Grover, L. E. Grinter, H. D. Hussey, B. G. Johnston, J. Jones, C. Kreidler, H. W. Lawson, Bureau of Ships (Code 350, John Vasta and E. M. MacCutcheon), N. M. Newmark, A. E. Poole, C. E. Webb, and W. H. Weiskopf.

§ See references 1 and 17-29.

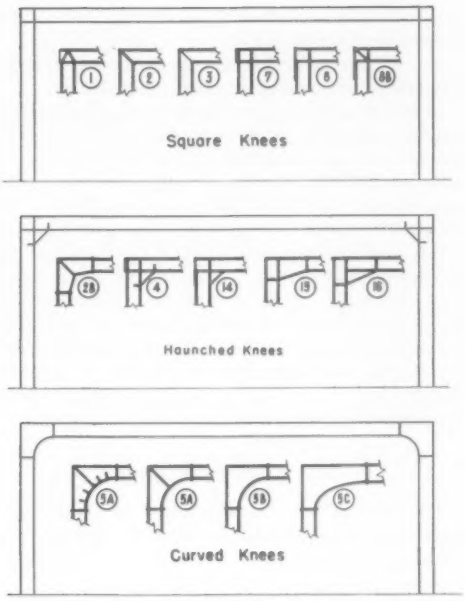


Fig. 4 Classification of portal frame knees into types

the various types are arranged as square (or straight), haunched and curved inner flange knees.

The research program developed to study some of these types will be discussed below.

II. REQUIREMENTS FOR CONNECTIONS

Before proceeding with a discussion of the test program and a presentation of test results, it is considered of value to examine the requirements imposed on continuous connections by implied or stated design assumptions. For example, some knees designed to be "rigid" may actually behave in a "semirigid" manner causing a redistribution of bending moments to overload some other part of the structure.

These requirements for corner connections will now be reviewed for two cases: (*a*) plastic analysis and design and (*b*) elastic analysis and design.

Present day engineering structures are safely designed according to elastic concepts based on a maximum "working" stress at a specified value below the yield point. According to Baker[20] and others, elastic design methods are irrational in many respects and thus cannot lead consistently to the most economical use of steel. For complex indeterminate structures, simplicity of analysis and design is a further advantage of plastic methods when compared with those elastic procedures which attempt to be completely rational. Consequently, methods of design based on the true, ultimate or "collapse" load-carrying capacity of the structure have occupied the attention of researchers and engineers alike in recent years.

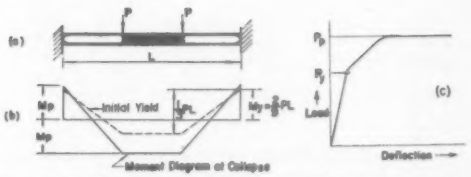


Fig. 5 (a) Fixed-ended beam under third-point loading; (b) moment diagrams at initial yield and collapse; (c) diagrammatic load-deflection curve up to collapse

In Appendix A some plasticity concepts have been reviewed in order to demonstrate the requirements of knees. Summarizing the discussion:

(*a*) For a fixed-ended beam of WF shape, loaded at the third-points, the ultimate load-carrying capacity is about 50% greater than the load at initial yield (Fig. 5). Theoretically, this percentage will be less in portal frames whose columns will afford less end restraint than the complete fixity assumed.

(*b*) The knee must be capable of resisting at the corner the full plastic moment, M_p, of the rolled sections joined.

(*c*) For straight knees the stiffness (or "rigidity") should be at least as great as that of an equivalent length of the rolled sections joined. Depending upon the proportions of the frame and the deflection limitations, additional flexibility in the knee may not be objectionable so long as requirement (*b*) is satisfied within the limit established in (*d*) below.

(*d*) The knee may be required to absorb further rotations at near-maximum moments after reaching the plastic hinge condition. This property has been termed "rotation capacity." The precise requirement depends on the degree of restraint, the loading and the length-depth ratio of the portal beam. In the case of a uniformly loaded beam, fixed at the ends, a connection must have a rotation capacity of about eight times the total rotation at initial yield, providing the length-depth ratio is thirty.

No requirement has been listed for haunched knees since it is not clear that plastic design is suited to frames with built-up connections.

The above requirements may be summarized for a square knee by stating that it must be as stiff and as strong in bending as an equivalent length of rolled

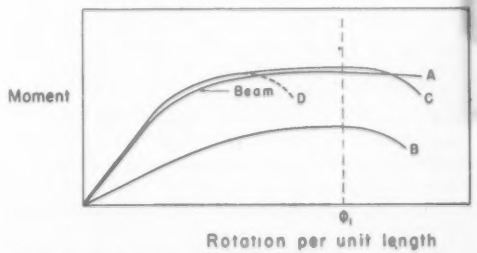


Fig. 6 Hypothetical behavior of connections with varying stiffness and rotation capacity

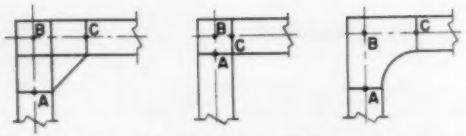


Fig. 7 Equivalent lengths (AB + BC) for three knee types

section, with adequate rotation capacity is governed by degree of restraint, loading and proportions of members.

Figure 6 illustrates some of these requirements. The moment-rotation curves of three hypothetical straight connections (curves *B*, *C* and *D*) are compared to that of a beam (*A*) for an "equivalent length."* Curve *C* typifies the behavior of a knee which develops the strength and stiffness of the rolled section. If ϕ_1 indicates a required minimum rotation capacity, then curve *C* also indicates that the connection will rotate sufficiently to allow all necessary plastic hinges to form. Curve *B* indicates an unsatisfactory connection because it develops neither the plastic moment strength nor the rigidity of the rolled section. The behavior typified by curve *D* (dotted) would be regarded as unsatisfactory for plastic design since such a connection would not have adequate rotation capacity for the given problem as indicated by the location of ϕ_1.

The elastic analysis and design of complicated types of rigid frames may be a task requiring considerable ingenuity. Of course, numerous methods of analysis for indeterminate structures are available such as moment distribution, slope-deflection, column analogy and energy methods.

In elastic design, when the loading, span and height are fixed, the portal frame is first proportioned arbitrarily. It is then analyzed using one of the methods mentioned above, and the induced stresses are checked. In no instance are the stresses in any component of the frame allowed to exceed a specified working stress. Members with higher stresses than the allowable are redesigned. A new analysis may be made after the revisions if the frame is considerably different from the original one.

Keeping in mind the working stress concept, the requirements imposed on the behavior of connections by elastic design are:

(*a*) A straight connection must be as strong as the lighter of the two beams joined (in the case of dissimilar members). The flexural yield moment, M_y, modified for direct stress, constitutes the strength criterion.

(*b*) The connection stiffness must be at least as great as that of an equivalent length of the rolled sections joined. A "semirigid" connection (if assumed rigid) will allow greater stresses than calculated to occur elsewhere in the structure.

(*c*) There is no requirement for a reserve "rotation capacity," although ductility is desirable as a safeguard against brittle failure.

(*d*) A haunched connection must develop its yield strength as computed by available elastic theory.

In special cases, fatigue resistance and esthetics may be additional design requirements which will dictate the use of built-up connections. Normally the use of haunched and curved knees also allows the designer to save material, since lighter beams and columns may be specified.

One of the principal requirements of all engineering construction is economy. High rigidity and strength invariably may be obtained by the use of more material. However, connections must be designed to have these desirable qualities with the least cost for material and for fabrication. Otherwise the savings in material brought about through designing for continuity will be outweighed by expensive joint details.

III. TEST PROGRAM

The following is a short description of the test program which is outlined in Figs. 8 and 9. A number of connection types are shown in Fig. 4.

Test Specimens

The knees tested are of types 2, 2B, 4, 5A, 7, 8B, 15 and 16, as illustrated in Figs. 8 and 9. A number of the selected types were proposed by various members of the Lehigh Project Subcommittee, which supervised the investigation.

It will be noted that the connections group themselves into three categories: (1) square, or straight, (2) haunched, (3) curved. Within each category a number of alternatives as to details are open to the designer, and such fabrication details may have a significant effect on behavior. The details and the factors involved in selecting each type are discussed in Section VI with information regarding the results of each test.

Two 8B13 rolled members joined at right angles formed the basis of connections *A* to *N*.

Connection *P* was formed by joining an 8WF31 column section to a 14WF30 beam section. In all cases the lengths of the two arms were equal, resulting in "45° loading."

The sequence of testing was as follows:

(*a*) Connection *P* (8WF31 and 14WF30).
(*b*) Connections *A* to *N* (8B13).
(*c*) Control beam.
(*d*) Coupon specimens.
(*e*) Connections *A* to *N* loaded in "tension."

The results of tension tests of connections will be reported in a later paper. The "compression" tests reported upon here constitute a more severe loading condition than that obtained when the ends are pulled in tension. In some frames, however, the connection is under "tension" loading as the collapse load is approached. For this reason, the connections were tested

* The equivalent lengths, $AB + BC$, of some typical connections are shown in Fig. 7.

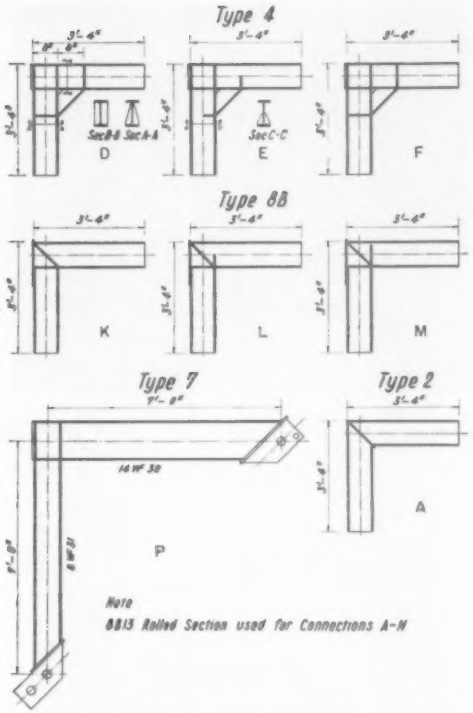


Fig. 8 Types 2, 4, 7 and 8B connections used in experimental program

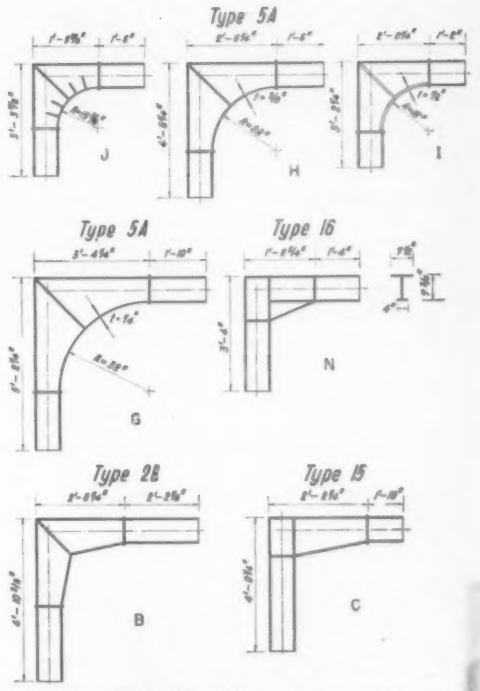


Fig. 9 Types 2B, 5A, 15 and 16 connections used in experimental program

in 45° "tension" after the compression tests had been completed.

After completion of test *P*, it was considered advisable to use a lighter rolled section than the 14WF30 and to use the same section for both legs of the connection. Such an arrangement would result in lighter specimens which could be moved easily by hand. Also it would furnish much of the desired data as to the influence of variation in details with a minimum of expense and time. An 8B13 rolled section was chosen because of its geometrical similarity to the 14WF30 shape already under investigation.

IV. COST OF FABRICATION

To obtain information on the relative cost of fabrication, the welding and cutting operations were carefully timed. The results are based on only one connection each, fabricated under special conditions and should therefore be considered only as approximate.

It was impracticable to determine accurately the entire labor cost of fabricating each knee. However, the data taken on oxyacetylene cutting and arc welding time is believed to be expressive of the comparative costs of fabrication of the knees.

In preparing plate stiffeners it was assumed for the sake of uniformity that they were taken from the middle of larger plates and that therefore a cut was to be made on every edge. Accordingly, adjustment was made in the time.

The time for welding includes time elapsed from the moment the arc was started to the instant the arc was stopped for each individual weld. For the $^{3}/_{16}$-in. fillet welds, the approximate rate of welding was about 10 in. per minute.

All specimens were fabricated in Fritz Engineering Laboratory by experienced fitters and welders on a part-time arrangement with the Bethlehem Steel Co. A d-c. straight polarity welding machine was used with E6012 electrodes.

Figure 10 shows the relative cutting and welding times, the shaded areas being for the cutting times. These bars represent the actual operations and do not include stops to change positions, electrodes, etc. The bar for knee *A* has been given a length of unity and the remaining bars have been given proportionate lengths, the proportion being stated at the end of each bar.

Knees *A*, *K*, *L* and *M* constitute the group having the simplest details. The fact that connection *A* is the least expensive as fabricated for this investigation does not necessarily mean this would be true if a large number of these were to be fabricated. In such a case, special devices would be necessary to make the 45°

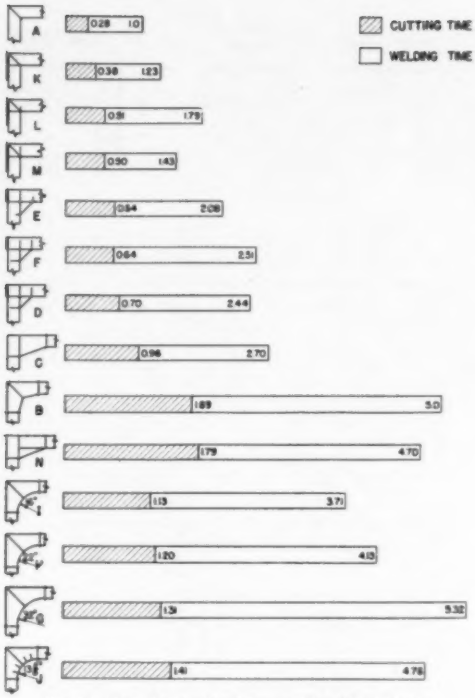


Fig. 10 Bar chart of cutting and welding times

bevel cut. Knees *L* and *M*, differing from *K* only by the addition of a pair of stiffeners, cost very little more to fabricate.

The cost of fabricating bracketed knees, *D*, *E*, *F* and *B*, *C*, *N* may also be studied as a group but it is not correct to compare their costs with those in the first group, because the bracketed knees have economical advantages not shown in the bar chart.

The curved knees, *I*, *H*, *G* and *J*, generally show increased cost of fabrication with increase in knee length, the exception being knee *J* which was provided with numerous radial stiffeners.

V. TEST APPARATUS AND TEST PROCEDURE

Connections *A*, *C*, *D*, *E*, *K*, *M* and *N* were tested in a 300,000-lb. hydraulic machine. *B*, *F*, *G*, *H*, *I*, *J* and *L* were tested in an 800,000-lb. screw-type machine. Figures 11 and 12 show each method of loading. The loads were applied through interchangeable loading fixtures.

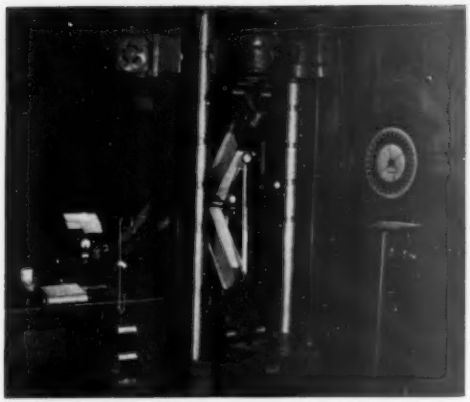


Fig. 11 Connection K—Test setup and instrumentation in 300,000-lb. machine used for tests A, C, D, E, K, M and N. Note the deflection gage, level bars, the loading fixture and the strain indicator used with a.-c., d.-c. converter

Connection *P* was tested by the scheme shown in Fig. 13 using an hydraulic jack to apply the load which was measured with an aluminum tube dynamometer. Special end fixtures were designed to provide pin-end loading conditions, and these were welded to the ends of the two members. The connection under test is shown in Fig. 14.

Lateral Support

All connections have sufficient torsional rigidity to require no lateral support in the elastic range. Once yielding commences, however, the lateral buckling strength is markedly reduced.

Three methods for providing lateral support were used in this program.

(*a*) For Connection *P*, Fig. 14 shows the I-beam lateral supports which are clamped to the base beam at the lower end and tied to a crossbeam at the top. The test member slides vertically between the guides. The distance between lateral supports at top and bottom was regulated with turnbuckles. This connection was held in position longitudinally as shown in Fig. 13.

(*b*) Connections tested in the 300,000-lb. hydraulic machine were laterally supported as shown in Fig. 11, the detail at the haunch being similar to that shown in Fig. 15. Again, the member slides between vertical guides. The supporting angles were bolted to a base-beam at the lower end and to two pairs of diagonals at the upper end.

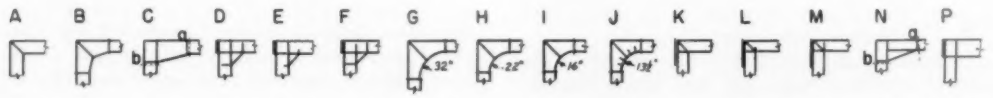


Fig. 12 Connection G—Two extra pairs of lateral support bars used at the ends of the knee. Yield lines developed on the curved flange. Collapse condition shown in Fig. 48

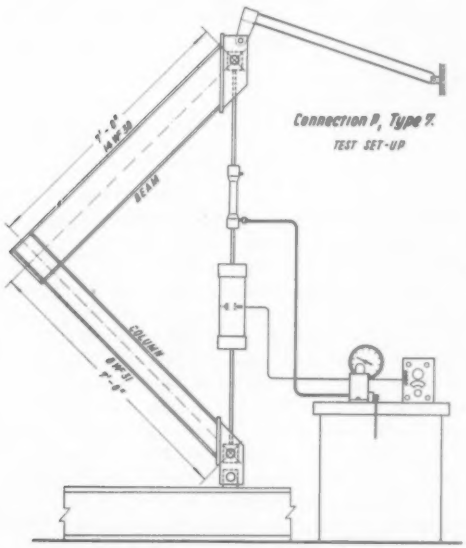


Fig. 13 Test setup for Connection P

Connection *B*, tested in the 800,000-lb. machine, was provided with similar lateral supports except that I-beams were used as in (*a*) above, being tied to the machine columns at the upper end (Fig. 15).

(*c*) The remaining connections (*F, G, H, I, J, L*) tested in the 800,000-lb. machine were laterally supported with two pairs of flexible bars. One end of each bar was welded directly to the specimen; the other was anchored to the testing machine frame. Bars were prestressed to about 300 lb. tension at the beginning of the test. SR-4's and Huggenberger gages were used to measure the forces. Lateral bars and gages are visible in Figs. 16 and 12. Because of the extra length of the curved knee, four sets of lateral support bars were used in Connection *G* (Fig. 12).

Method (*c*) was the most satisfactory.

Measurements

Deflection was measured with one dial gage on Connections *A* through *N* as shown in Figs. 11 and 12. For Connection *P* dial gages were supported on a special frame which was referenced to the neutral line of the 14WF30 beam at its ends (Fig. 14).

Fig. 14 Connection P—Test setup showing lateral and longitudinal supports, hydraulic jack, dynamometer, pump and the dial gage support frame

Fig. 15 Connection B—Lateral support guides for Connection B. Moment—540 in.-kips. Yield lines have been developed. Connection at failure shown in Fig. 40

Fig. 16 Connection I—Lateral support system typical for connections F, G, H, I, J and L tested in the 800,000-lb. machine. Bars tied to the beam shown on the right. Yield lines developed symmetrically in both tension and compression flanges and in the web. Detail in Fig. 49

The change in the average length of moment arm was measured in all tests. The mirror gage used may be seen in the lower part of Fig. 18. The wire, supported at the outside of the knee, is stretched across the mirror by a plumb bob. This measurement is the basis for later corrections to knee moments.

Dial gages were used on some connections to measure lateral and local buckling at critical points (Fig. 18).

Relative rotations were measured with level bars, the use of which has been described in other reports.[7] To measure rotations in the knee, the supports were located at the ends of the rolled section so that the rotation measured is that occurring over the "equivalent length" $AB + BC$ as previously discussed and shown in Fig. 17. Two types of supports were used for the level bar, the second of which is the most satisfactory.

Extensive strain measurements were made with SR-4 gages on Connection *P*. On each of the remaining connections an average number of eight gages of the A-11 type were used.

Whitewash was used to reveal the flaking of mill scale that follows the formation of Luder's lines at the yield point.

Test Procedure

Prior to the beginning of each regular test a load

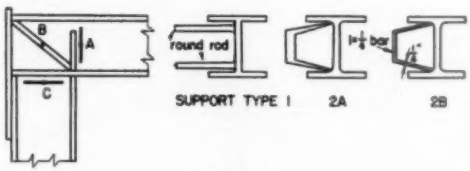


Figure 17

equal to about 25% of the expected yield load was applied. This load was then removed and reapplied, a few measurements being made to ascertain that any friction in the system was negligible.

Once begun, the tests were continued to collapse without interruption, involving a period of from 24 to 48 hr. After yielding occurred, load increments were reduced to about 3% of the maximum load. In the inelastic range, readings were taken according to a criterion which assured that all significant plastic flow had taken place under constant load prior to the recording of test data and application of a new load increment. For connections *A* through *N* this "criterion" was 0.0015 in. of deflection in a 15-min. period as indicated by the dial gage, the load being maintained constant.

Fig. 18 Connection L—The dial gage used to detect flange local buckling and Huggenberger tensometers used to measure lateral forces are shown

Preparation and Control of Specimens

All specimens were tested in the as-delivered condition, and the rolled sections for series *A* through *N* were cut from the same rolling.

Physical properties were determined from 25 tensile coupons and five compression specimens cut from the rolled shape and the plate material used in fabricating the built-up specimens.

A 12-ft. length of beam cut from 8B13 stock was tested as a "control beam" under third-point loading with the ends simply supported.

VI. TEST RESULTS

The test results have been arranged in sections according to the general type of connection, that is, square, haunched or curved. Within each section are discussed the fabrication details, moment-rotation characteristics, deflection relationships, yielding, modes of failure and instability. Stress-distribution data are presented in part and only for Connection *P*.

1. Square Knees

(*a*) *Fabrication Details* (*Figs. 4 and 8*)

Connection P, Type 7, was considered because it has been frequently used in practice and is regarded as an economical type to fabricate. The sections (8WF31 and 14WF30) were selected as typical of those used in actual construction. The 8WF31 member was tested as a simple beam without lateral support and the results reported by Luxion and Johnston.[6] Tests of the 14WF30 member as a continuous beam were also carried out at Lehigh University.[21]

The stiffeners which extend the column flanges were beveled upon the advice of fabricators who indicated this to be standard practice when large quantities are involved. It eliminates the necessity for separate fitting of each stiffener, the $^1/_8$-in. opening at each end being adequate to allow for within-tolerance variation in section dimensions.

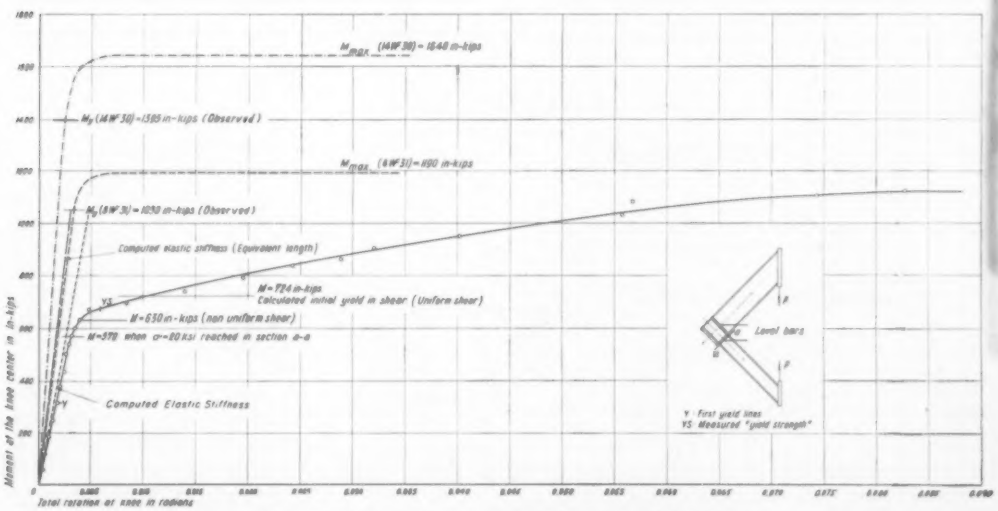

M_{max} (14WF30) = 1540 in-kips
M_y (14WF30) = 1305 in-kips (Observed)
M_{max} (8WF31) = 1190 in-kips
M_y (8WF31) = 1030 in-kips (Observed)
Computed elastic stiffness (Equivalent length)
M = 724 in-kips
Calculated initial yield in shear (Uniform shear)
M = 630 in-kips (non uniform shear)
M = 570 when σ = 20 ksi reached in section a-a
Computed Elastic Stiffness
Moment at the knee center in in-kips
Total rotation at knee in radians
Load bars
Y : First yield lines
YS Measured "yield strength"

Fig. 19 Moment-rotation curve. Connection P, Type 7

On all the remaining square knees the use of square-cut edges and fillet welding prevailed.

Connection A, Type 2, is similar to the connection at the apex of gabled-roof frames and seems to be economical and simple. Comparison with other square-knee types is, of course, intended. The diagonal butt plate has the same thickness as the flanges. The arrangement of the diagonal stiffener is favorable to the transmission of compression flange forces.

Connections K, L and M, Type 8B, constitute a series based on an arrangement originally suggested to the authors by Jonathan Jones. No special cutting of the rolled section is involved and all welds are fillet welds. The necessity for field cutting has been minimized. *K* is reinforced with a diagonal stiffener only, while *L* and *M* are supplied with vertical sniped stiffeners either half-depth or approaching full-depth. The influence of the various stiffener arrangements on connection behavior is of interest.

(b) *Strength and Stiffness*

Two important objectives of this present investigation were to obtain data on strength and rigidity (or stiffness). Such behavior may be examined in the moment-rotation and moment-deflection curves.

Connection P. In Fig. 19 the moment-rotation curve for this connection is shown.* Moment is computed about the intersection of the neutral lines, rotation being measured by two level bars at locations shown in the sketch. The curve deviates from a straight line at about 500 in.-kips. Comparison with the 8WF31 and 14WF30 M-ϕ curves is shown.

These comparison curves are determined from previous beam experiments, the measured angle change per unit length, ϕ, having been multiplied by the equivalent length of knee, ΔL. The equivalent lengths are different for the two beams since the curves are computed assuming that equal members are being joined. The "real" curve should be somewhere between the two dashed lines.

Taking into account both bending and shear deformations, the theoretical elastic line is also shown in Fig. 19.*

The moment is shown at which a stress of 20 ksi. is reached at the end of the knee indicating a factor of safety of about 1.0 against inelastic behavior.

Even though the rotations are very large at collapse, the maximum load-carrying capacity does not reach that determined for the weaker of the two beams, in spite of the fact that the connection is loaded under a condition conducive to strain hardening. (Figure 21 indicates the extent of deformation at the maximum load.)

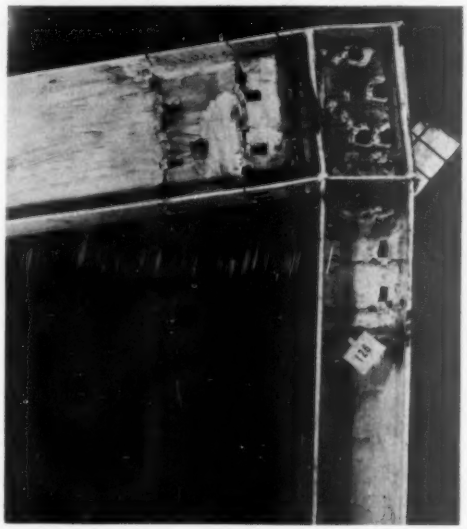


Fig. 21 Connection P—Distortion of the knee at the end of test

In Fig. 20 is plotted the over-all deflection of the connection as measured by Gage 1.

The moment corresponding to the load at which yielding should commence in shear has been computed in Part II and is indicated in Figs. 19 and 20 as M = 630 in.-kips.

Connections A, K, L and M. Moment-rotation curves for these straight knees are given in Fig. 22.

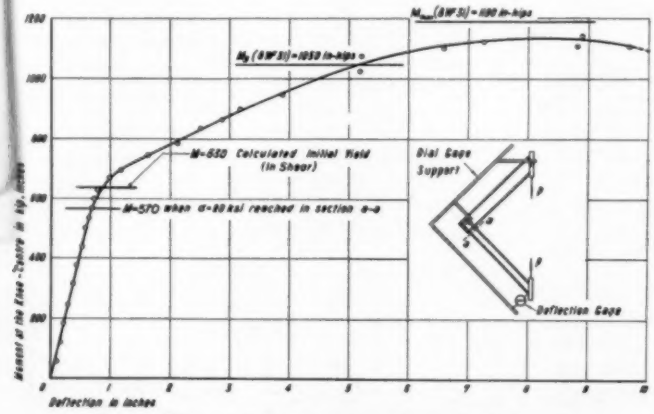

M=630 Calculated Initial Yield (In Shear)
M=570 when σ=20 ksi reached in section a-a
Dial Gage Support
Deflection Gage
Deflection in Inches

Fig. 20 Moment-deflection curve. Connection P, Type 7

* In all curves, except Fig. 52, moment has been corrected for the measured increase in moment arm in the plastic range.

* Computation for theoretical curves are contained in Part II of this report, to appear in a later issue of this JOURNAL.

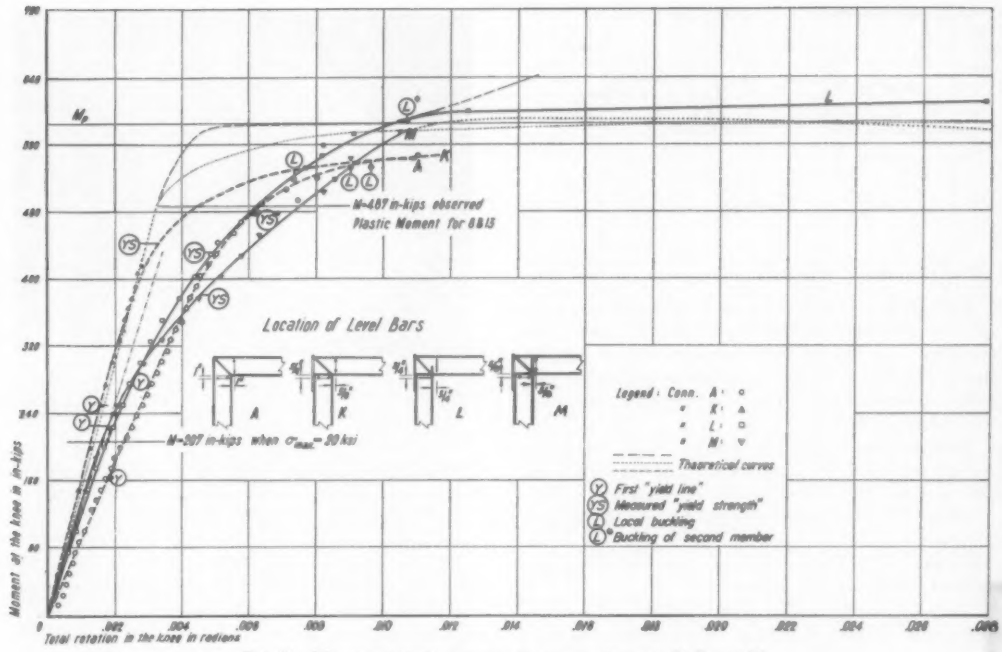


Fig. 22 Moment-rotation curves for connections A, K, L and M

Difficulty was encountered with the rotation measurement device for A, K and M, round bar supports having been used. The theoretical relationships for the elastic and plastic portions are shown by the dashed and dotted lines.

The moment-deflection curves appear in Fig. 23. Again there is plotted the moment at which a theoretical stress of 20 ksi. is reached at the knee.

Tests K and A were stopped when the apparent maximum load was reached. Tests L and M, however, were continued beyond the maximum until deformations became relatively large.

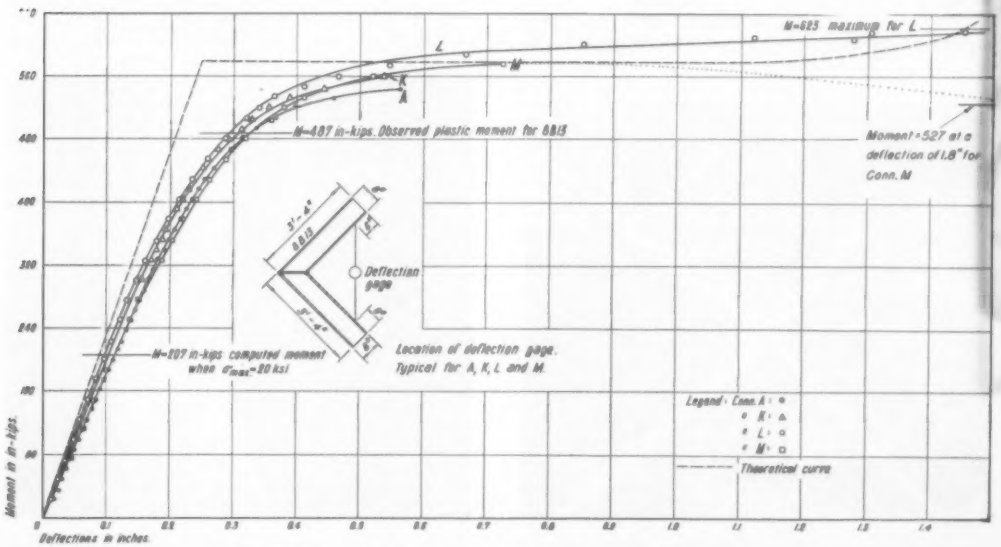

M=625 maximum for L
M-487 in-kips. Observed plastic moment for 8B13
Moment=527 at a deflection of 1.8" for Conn. M
Deflection gage
M-207 in-kips computed moment when σmax=20 ksi
Location of deflection gage. Typical for A, K, L and M
Legend: Conn. A
K
L
M
Theoretical curve
Moment in in-kips
Deflections in inches

Fig. 23 Moment-deflection curves for connections A, K, L and M

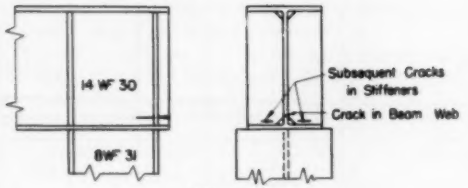


Figure 24

(*c*) *Yielding and Mode of Failure*

Connection P. At a moment of about 300 in.-kips. (27% of maximum moment) the first yield lines were observed. As can be seen from Fig. 19 this yielding has no effect on deflections or rotations, although it may influence local strains. These lines occurred within the knee panel in the web.

Yielding which could be detected with measuring instruments used was observed at a moment of about 500 in.-kips. (45% of maximum load carried). This yielding took place at the web in the center of the knee as expected, distinct yield lines being observed in the whitewash. On further loading, these yield lines increased in number and thickness.

The load was decreasing when the limit of the straining mechanism was reached, and the test was stopped.

Yielding was observed in both flanges of the column close to the knee. In the compression flange one line was observed about 14 in. along the column away from re-entrant corner. Only local yielding was observed in the beam, extending about 2 in. away from the knee.

There were two other aspects of the failure which should be mentioned:

(*a*) Local buckling of the 14WF30 compression flange was first observed at $P = 17$ kips. ($M = 1080$ kip.-in.). The local deformations were symmetrical and were not excessive. On further loading, the flange

Fig. 25 Connection P—Local buckling of compression flanges at re-entrant corner

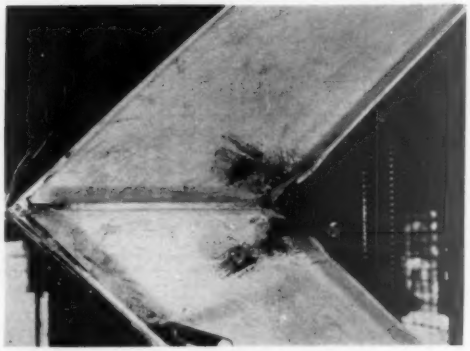


Fig. 26 Connection A—Yield lines and local buckling of the flanges at collapse. Yield lines appeared first in the web near the exterior corner. Round rod level bar supports were modified for later tests

of the column also buckled, the deformations of this flange being smaller than those of the beam (Fig. 25).

(*b*) After considerable additional deformation in the knee had occurred and at about the maximum load, a crack started at the root of the lower beam fillet. The location is shown in Fig. 24. With further deformation, the crack opened, extended about 2 in. into the knee, and initiated cracks in the end stiffener plates. The fracture involved considerable necking of the web plate.

Connections A, K, L and M. Figures 26–29 show the mode of failure for these types. After yielding had progressed sufficiently, the compression flanges buckled locally. This was followed by buckling of the web bringing about failure of the connection by lateral deformation out of the plane of the knee. In Fig. 22 the points of observed local buckling have been indicated.

The lateral deflections measured in the web for Connection *L* are given in Fig. 30. The force required to

Fig. 27 Connection K—Local buckling in the compression flange of the beam at end of test

Fig. 28 Connection M—Local buckling occurred after considerable yielding. Yield lines proceeded about 8 in. from the connection in both legs

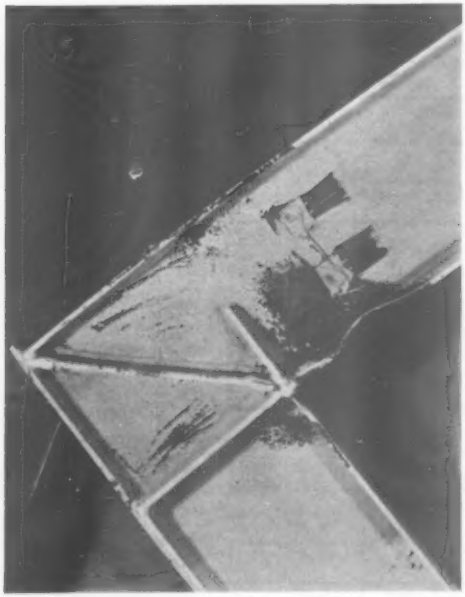


Fig. 29 Connection L—Mode of failure showing local buckling at the end of the test, "yield" due to shear in the web and tension face plate yielding. Strengthening effect of face plate on vertical member is to be noted

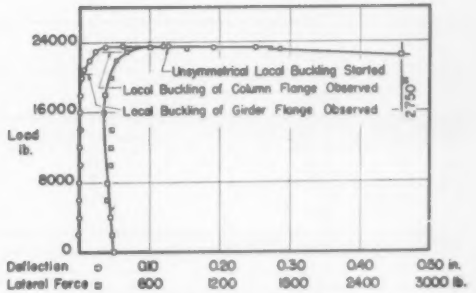


Fig. 30 Lateral deflections and lateral forces, Connection L, Type 8B

keep the flanges in position is also shown in Fig. 30. In Fig. 31 is plotted the local buckling curve as obtained from the dial gage shown in Fig. 18. At the end of the Connection *L* test, the maximum lateral force was 2750 lb., about 12% of the maximum applied load.

The final mode of failure was by instability due to local and lateral buckling.

For connections *A* and *K* in particular, local buckling was not symmetrical—i.e., a definite "wave" occurred on one side of the web but not on the other (Fig. 27). A more symmetrical pattern was exhibited in connection *M* (Fig. 28) and in the test of connection *L*. The flex bars used were adequate to induce symmetrical local buckling (Fig. 29).

(*d*) *Strain Distributions*

A more complete presentation of strain measurements is to be the subject of a later report, although some of the results from connection *P* are presented here.

The distribution of strain normal to each of six cross sections and for five loads is given in Figs. 32 and 33. The flange strains are averages obtained from the several gages installed. The theoretical strain distributions are shown by the dashed lines.

The strain variation along the flanges of the beam and column were plotted for three of these same loads. Figure 34 presents the longitudinal strain distribution along the 14WF30 beam flanges. The maximum strain occurred above the stiffener. Figure 35 shows the strain distribution in the column flanges.

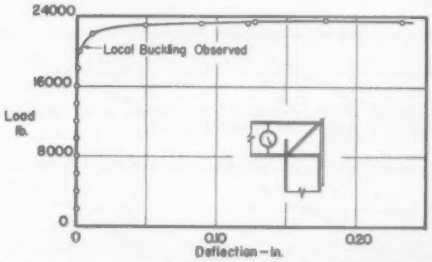


Fig. 31 Load-flange buckling curve for Connection L, Type 8B

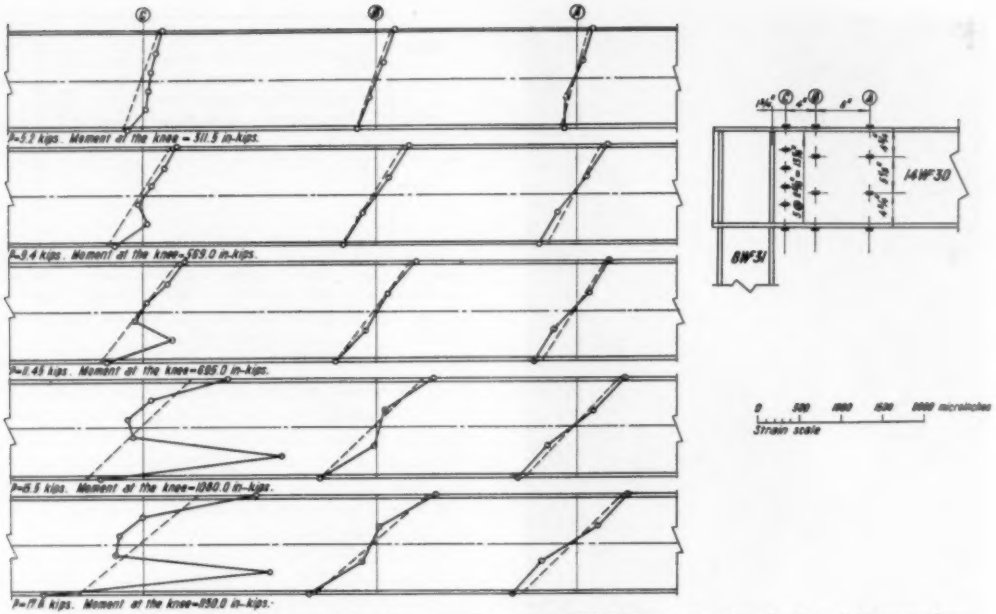

P=5.2 kips. Moment at the knee = 311.5 in-kips.
P=9.4 kips. Moment at the knee=569.0 in-kips.
P=11.45 kips. Moment at the knee=685.0 in-kips.
P=15.5 kips. Moment at the knee=1080.0 in-kips.
P=17.6 kips. Moment at the knee=1150.0 in-kips.
14WF30
8WF31
0 500 1000 1500 2000 microinches
Strain scale

Fig. 32 Comparison between theoretical and measured strains in 14WF30 beam at various loads and distances from connection

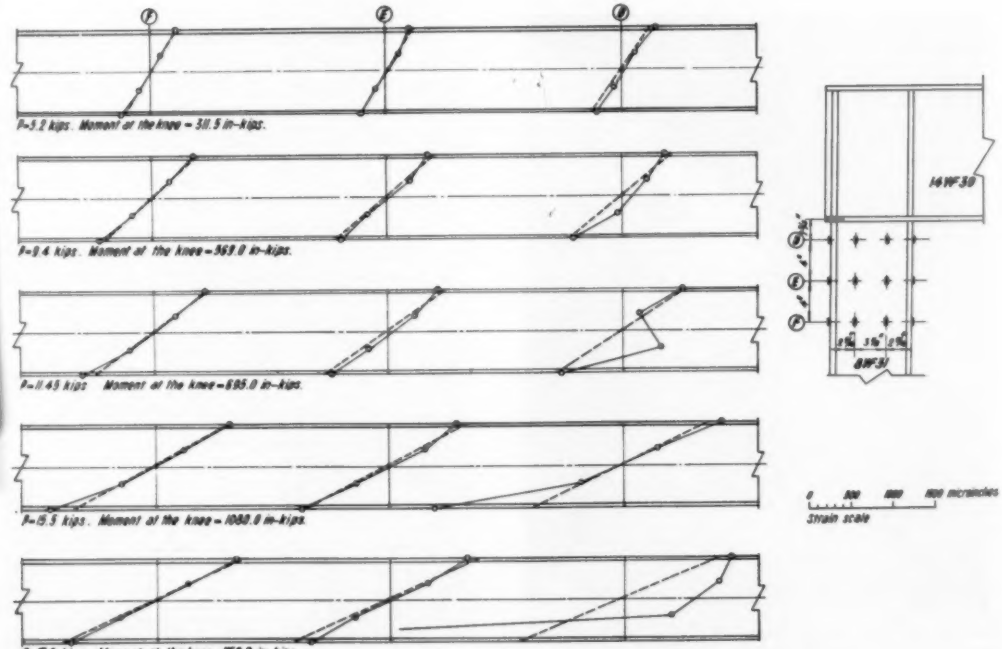

P=5.2 kips. Moment at the knee = 311.5 in-kips.
P=9.4 kips. Moment at the knee=569.0 in-kips.
P=11.45 kips. Moment at the knee=685.0 in-kips.
P=15.5 kips. Moment at the knee=1080.0 in-kips.
P=17.6 kips. Moment at the knee=1150.0 in-kips.
14WF30
8WF31
0 500 1000 1500 microinches
Strain scale

Fig. 33 Comparison between theoretical and measured strains in 8WF31 column

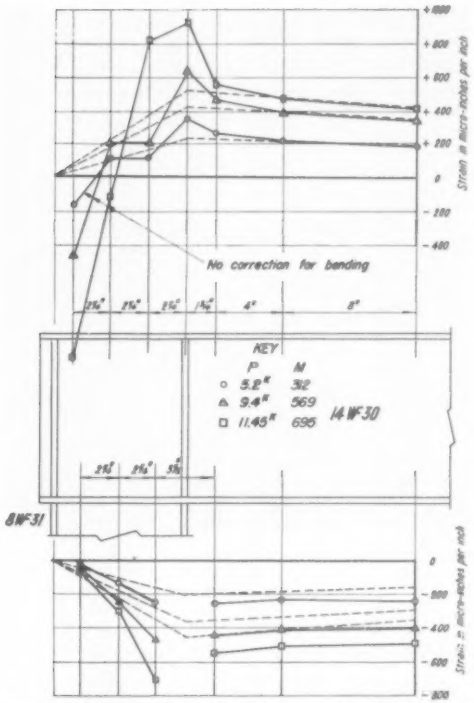


Fig. 34 Connection P, Type 7, longitudinal variation of normal strain in 14WF30 beam flanges

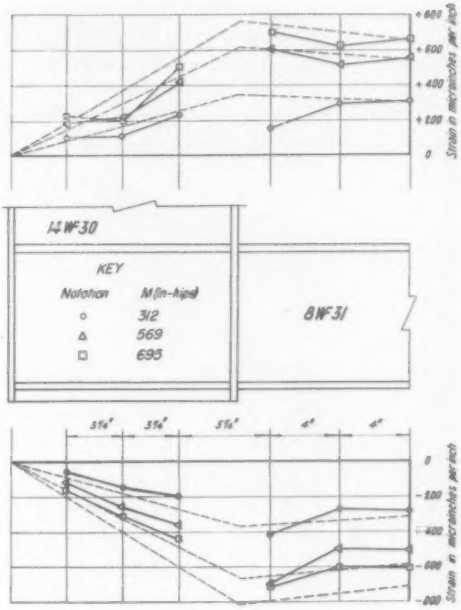


Fig. 35 Connection P, Type 7, longitudinal variation of normal strain in 8WF31 column

It should be noted that strains for the "tension" (upper) flange in Fig. 34 have not been corrected for local bending in the flange. Elsewhere, all strains have been measured on both sides of the flanges or stiffeners, and averages have been presented in which bending strains have been eliminated.

2. *Haunched Knees*

(*a*) *Fabrication Details* (*Figs. 4, 8, and 9*)

Connections D, E and F, Type 4, form a series based on a type suggested for inclusion in this program by the Navy Dept. It is used in practice to a considerable extent, as indicated in reference 18. The 45° diagonal bracket extends 8 in. along both the column and beam. The three specimens are alike except for the two outer stiffeners. In *D* and *E* the middle stiffener of the beam is a full stiffener welded to both flanges. The outer stiffener is sniped in *D* and half-depth in *E*. In *F* both intermediate and outer stiffeners are sniped. The purpose of this "sniping" is to decrease the cost of fabrication, the depth selected being adequate to clear the root of the fillet.

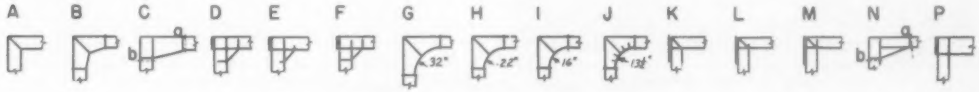
Connection B, Type 2B, was also selected from reference 18 and it appears often elsewhere in the literature. It bears a similarity to the Type 2 connection. The haunch was built up of $^1/_4$-in. plate material with a 1 to 5 slope of the inner flange.

Connection C, Type 15, is a modification of Type 7, the haunch with greater web area theoretically permitting higher loads before yielding due to shear would commence. The haunch, built up from $^1/_4$-in. plate material, has an inner flange slope of 1 to 3.

Connection N, Type 16, simulates the stiffener system for bulkheads and decks of ship structures. It is usual to assume that 30 times the thickness of the plating acts as a flange in flexure. Therefore for $^1/_4$ in. thickness, the upper flange width was made $7^1/_2$ in.

(*b*) *Strength and Stiffness*

Connections D, E and F. Moment-deflection curves are shown in Fig. 36. As in the case of some of the square knees, difficulties were experienced with level bar supports on Connection *D*. The detail moment-rotation curves have been omitted although average unit rotations are presented in Fig. 52. Two compari-



son points are plotted in Fig. 36: the theoretical moment to cause a stress of 20 ksi. in the compression flange and the observed maximum moment for the control beam test.

Connections B, C and N. Figure 37 presents the moment-deflection relationship. The haunched knees are not particularly related to one another, the "worst loading" condition requiring a different length of beam stub in each case. The original round-rod level support was used on *B* and *N* but modified for *C* (Fig. 41).

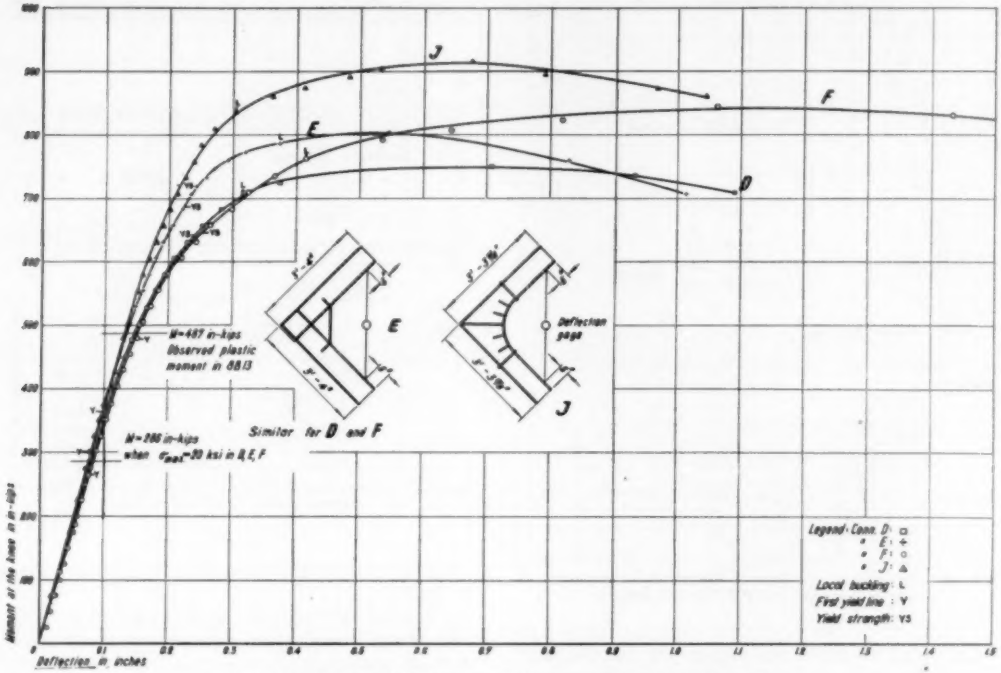


Fig. 36 Moment-deflection curves for connections D, E, F and J

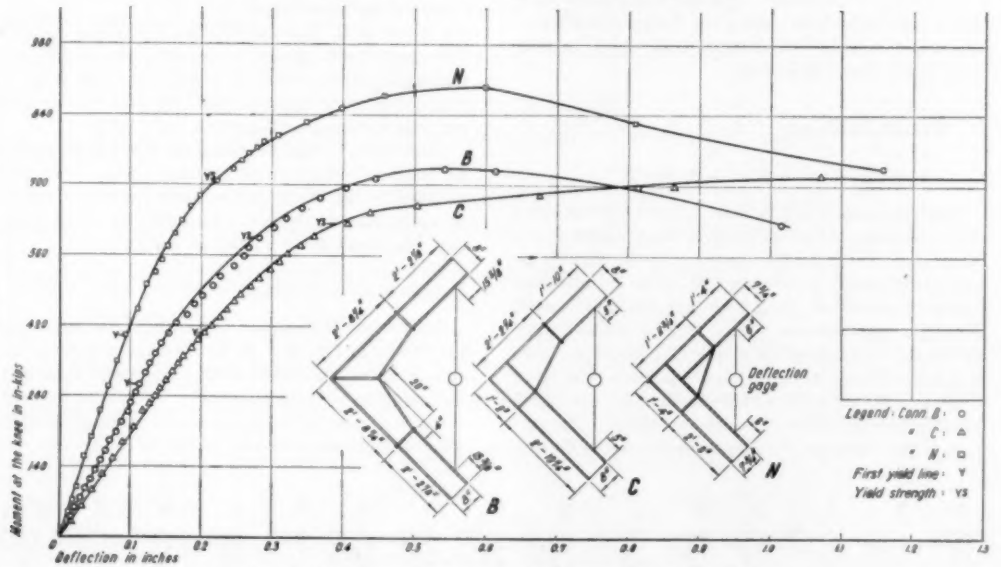


Fig. 37 Moment-deflection curves for connections B, C and N

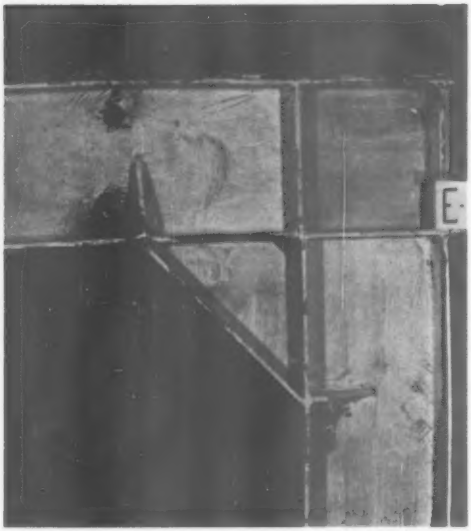


Fig. 38 Connection E—Deformation and yielding at end of test

(c) *Yielding and Mode of Failure*

Connections D, E and F. With the better lateral support used on *F*, an S-shaped lateral buckling contour was observed at collapse. Figure 39 shows Connection *F* at the end of the test. In spite of the additional knee area, slight yielding still occurs in the web. In Connection *D* there was no yielding in the three square web panels. Connection *E* exhibited somewhat more yielding than Connection *F* as is evident in Fig. 38.

Fig. 39 Connection F—Instability failure at end of test. "Symmetrical" local buckling

Fig. 40 Connection B—Yielding at end of test. Local buckling evident in compression flanges of built-up knee. Compare with Fig. 15, a detail at the re-entrant corner

Fig. 41 Connection C—Yield lines in the web of haunch and local buckling in the column

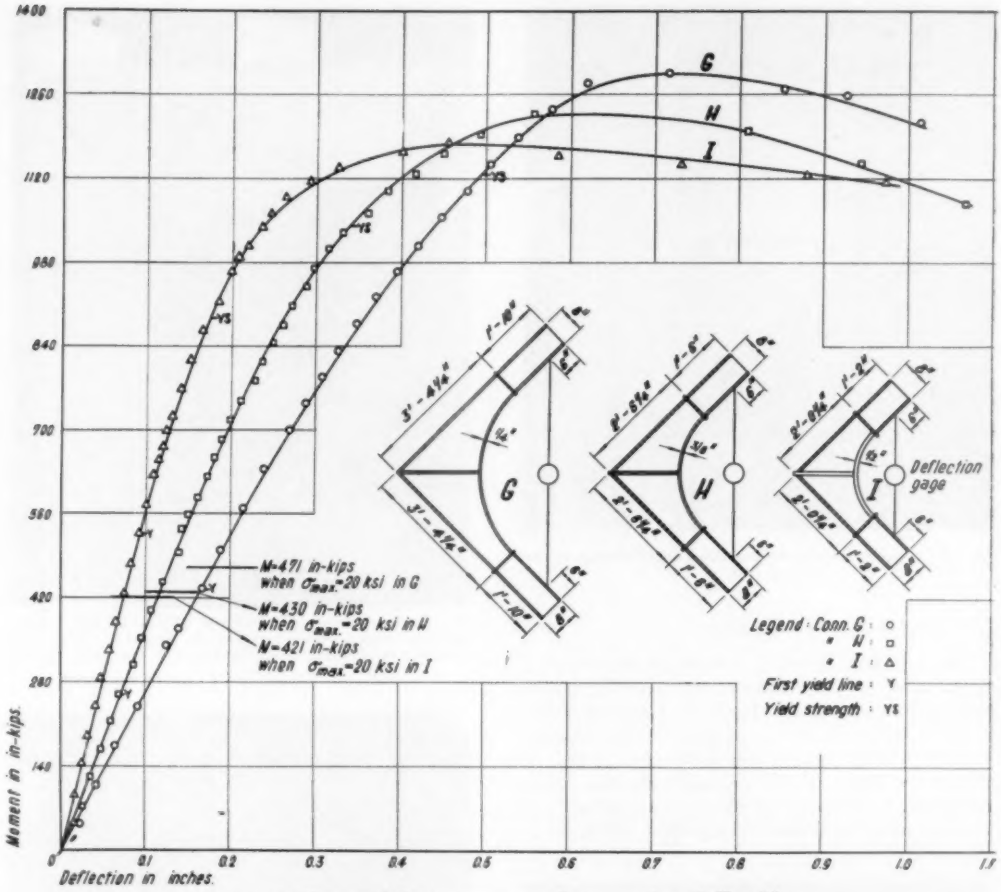


Fig. 44 Moment-deflection curves crop for connections G, H and I

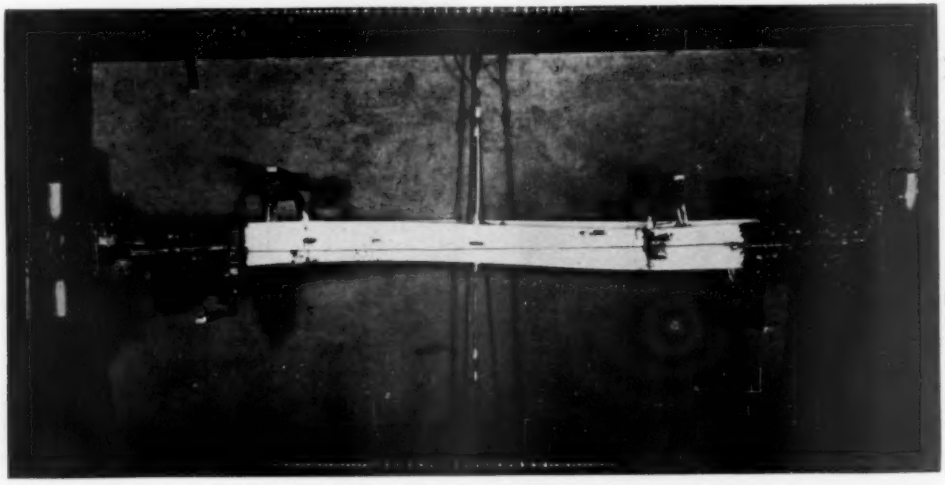


Fig. 45 Connection H—Permanent distortion of the connection at end of the test. Lateral support adequate to cause S-shaped collapse

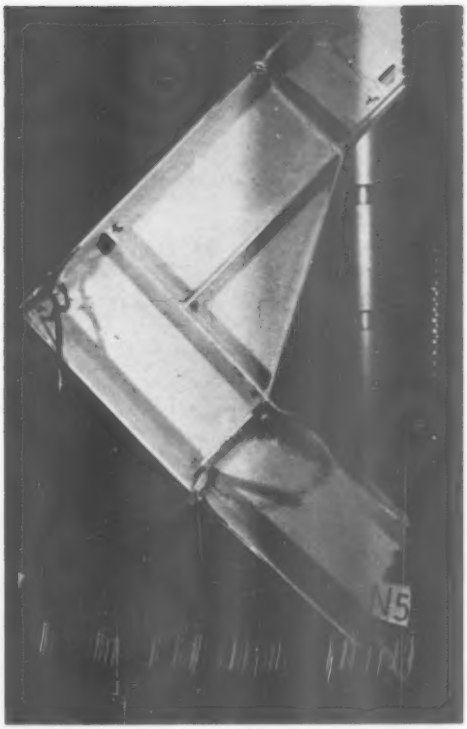


Fig. 42 Connection N—This figure shows yielding in the web of the "column" and local buckling of the flange

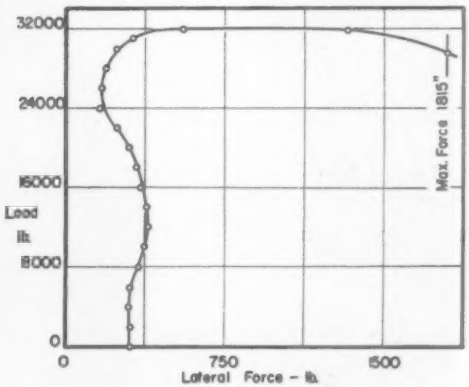


Fig. 43 Load-lateral force curve, Connection F, Type 4

The lateral forces measured by strain gages on tie bars are given in Fig. 43 for Connection *F*. The lateral force at maximum load reached 800 lb., increasing rapidly thereafter toward the end of the test.

Connections B, C and N. Final failure in all cases was by instability. Figure 40 shows the yield pattern in *B*. Figures 41 and 42 show Connections *C* and *N* after test. Local buckling of the flanges is evident in each figure.

3. *Curved Knees*

(*a*) *Fabrication Details (Figs. 4 and 9)*

Connections G, H and I were designed to study the influence of radius of curvature and thickness of inner flange. For a selected thickness of curved inner flange, the radius was proportioned approximately according to the recommendations of the A.I.S.C.[1] The resulting dimensions are shown in the figures.

Connection J has a smaller radius ($R = 13^5/_8$ in.) with an inner flange thickness of one-quarter of an inch. Tilting brackets were added in the curved portion. This connection was designed to be comparable to Connections *D*, *E* and *F*, Type 4, the minimum depth at the throat, measured from the exterior corner, having been selected to be identically the same as in the Type 4 connections. Because of this intended comparison, lengths of moment arms were also made identical.

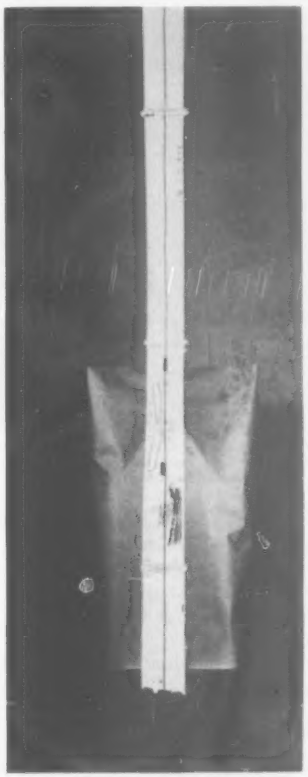


Fig. 46 Connection G—Permanent distortions were relatively small in this connection because of additional lateral support at haunch ends

(*b*) *Strength and Stiffness*

Connections G, H and I. The moment-deflection

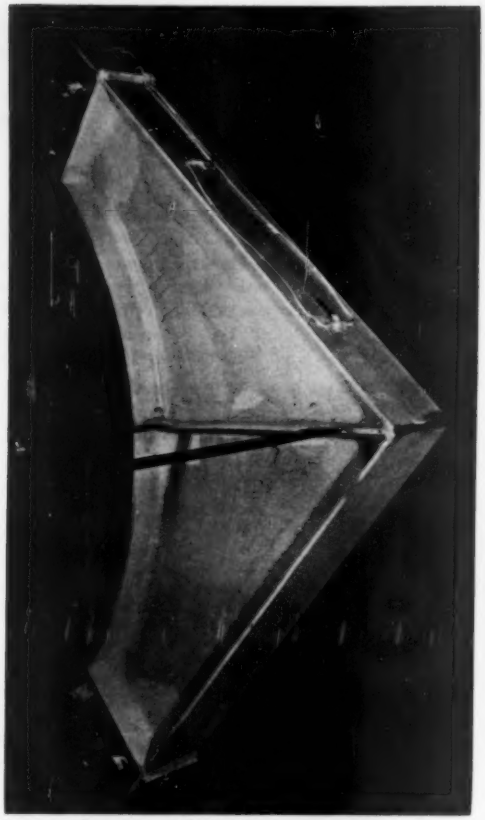


Fig. 47 Connection H—Uniform arrangement of compression yield lines is evident. A few tension lines are present in the upper flange

information is presented in Fig. 44. The load-carrying capacity decreased successively in *G*, *H* and *I*, the radius decreasing in the same order. In each test the improved level bar support system was used. Moments corresponding to 20 ksi. in the curved inner flange are plotted in Fig. 44.

Connection J. This has already been examined in Fig. 36 in comparison with Connections *D*, *E* and *F*.

(c) *Yielding and Mode of Failure*

Connections G, H and I. Figures 45 and 46 show the permanent lateral deflections at the end of the test of Connections *H* and *G*. The effectiveness of the extra sets of lateral support bars used on Connection *G* is evident. Yielding of the web of Connection *H* is shown in Fig. 47. The local buckling in the flange of Connection *G* is shown in Fig. 48.

In Connection *I*, lateral support was also adequate to cause S-shaped collapse similar to that shown in Fig. 45. The extensive yielding that took place is shown in Fig. 16. A close-up of the flange which has buckled locally is given in Fig. 49. Some yielding and local buckling also occurred in the flanges of the rolled section. In Fig. 51 the load-local buckling data is presented for Connection *I*.

Connection J. With a relatively small radius of curvature and $^1/_4$-in. curved flange, this connection is subject to larger cross-bending stresses than *G*, *H* and *I*. Local buckling developed between the stiffeners near the ends as shown in Fig. 50. Final collapse was again in the S-shaped form.

VII. SUMMARY OF TEST RESULTS

1. *Strength of Connections*

Table I presents the following summary information on the strength of each connection:

(*a*) Local yield (formation of first yield line).
(*b*) Initial yield (observed and computed).
(*c*) Maximum moment M_k, in the knee.
(*d*) Maximum moment, M_r, at the end of the rolled section.

Fig. 48 Connection G—Yield lines evident in compression flange. Local buckling caused final collapse

Fig. 49 Connection I—Detail at junction of rolled beam to built-up curved knee. Local buckling evident. This is a detail of Fig. 16

2. *Strength and Stiffness*

For connection *P* this information is presented in Figs. 19 and 20.

For connections *A* through *N*, the moment-deformation data is summarized in Fig. 52, the total measured rotations in the knee being divided by the equivalent length of each knee. These are termed, "average rotations," and are compared to the unit rotations measured in the rolled 8B13 section.

On all tests the M-ϕ characteristics were measured with strain gages along the member away from the knee. This data has not been presented, but good agreement was obtained in the elastic range.

3. *Cost of Fabrication*

The time for cutting and welding for connections *A* through *N* is indicated in Fig. 10. The total time required for connection *A* is the basis for comparison of the other types.

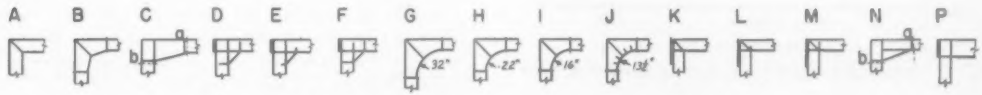
4. *Yielding and Mode of Failure*

The convenience in examining the behavior of the various knees, the following table lists the photographs contained in this report for each connection. In the third column are the figures in which moment-deformation curves are presented.

Table 1—Summary of Connection Strengths

		Initial yield moment, M_h, at the haunch					Maximum moment, M_h, at the haunch			Maximum moment	
Connection	Type	Observed first yield line, in.-kips.	Observed initial yield,* in.-kips.	Calculated, in.-kips.	Observed first line, / Calculated (Col. 3 ÷ Col. 5)	Observed initial yield, / Calculated (Col. 4 ÷ Col. 5)	Observed, in.-kips.	Observed / Calculated initial yield (Col. 8 ÷ Col. 5)	Observed $M_{max.}$ of control beam / (Col. 8 ÷ 487)	M_r, in rolled section: Observed, in.-kips.	M_r, in rolled section: Observed, / $M_{max.}$ = 487
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A	2	163	369	433	0.38	0.85	548	1.27	1.13	486	1.00
B	2B	305	380	750	0.41	0.51	728	0.97	1.50	346	0.71
C	15	402	563	524	0.77	1.07	720	1.37	1.48	M_{aa} = 353 M_{bb} = 555	0.72 1.14
D	4	477	477	587	0.81	0.81	751	1.28	1.54	492	1.01
E	4	364	472	587	0.62	0.80	804	1.37	1.65	526	1.08
F	4	264	276	587	0.45	0.47	844	1.44	1.74	552	1.13
G	5A	436	654	920	0.47	0.71	1296	1.41	2.66	482	0.99
H	5A	263	681	840	0.31	0.81	1228	1.46	2.57	490	1.00
I	5A	526	516	883	0.60	0.58	1180	1.33	2.47	472	0.97
J	5A	300	475	620	0.48	0.77	915	1.47	1.88	452	0.93
K	8B	251	316	433	0.58	0.73	560	1.29	1.15	496	1.01
L	8B	276	176	433	0.64	0.41	624	1.44	1.28	553	1.13
M	8B	226	216	433	0.52	0.50	576	1.33	1.19	511	1.05
N	16	402	577	606	0.66	0.95	894	1.47	1.84	M_{aa} = 390 M_{bb} = 591	0.80 1.21
P	7	311	493	630† 1195‡	0.49 0.26	0.77 0.41	1150	1.80 0.96	0.96§	1100	0.92§

† Shear.
‡ Flexure.
§ Ratio is based on 1190 in.-kips., the $M_{max.}$ of 8WF31.
* Point at which moment-rotation curve deviates from straight line.



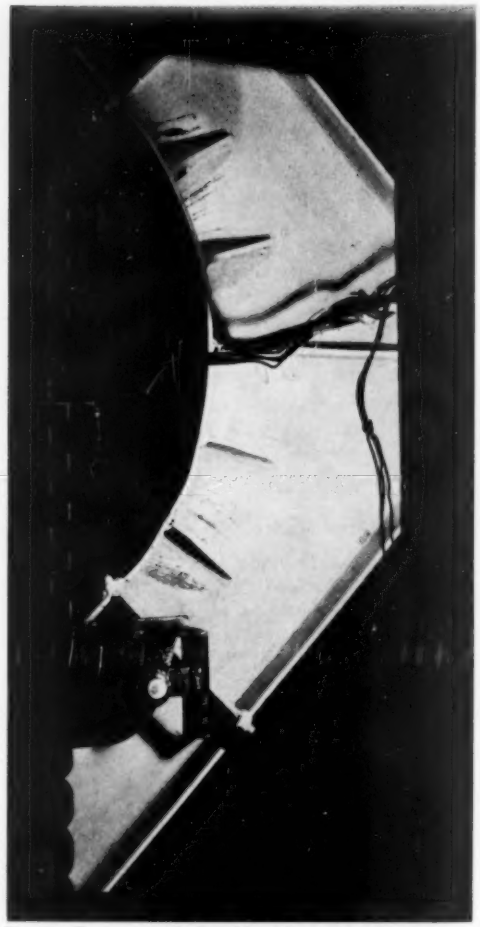


Fig. 50 Connection J—Local buckling and yielding occurs between stiffeners

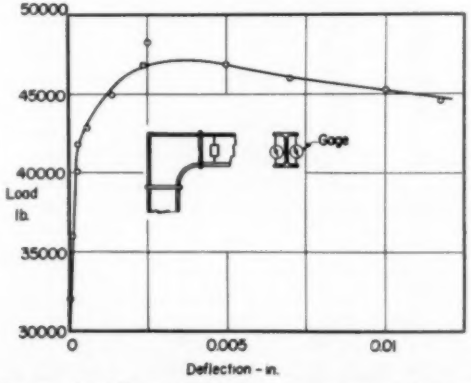


Fig. 51 Load-flange buckling curve, Connection I, Type 5A

Table 2—Table of Figure Numbers for the Various Knees

Connection No.	*Photographs*	*Moment-deformation curves*
A	26	22, 23
B	15, 40	37
C	41	37
D	...	36
E	38	36
F	39	36
G	48, 12, 46	44
H	45, 47	44
I	16, 49	44
J	50	36
K	11, 27	22, 23
L	18, 29	22, 23
M	28	22, 23
N	42	37
P	14, 21, 25	19, 20

Due to space limitations, Parts II and III will appear in later issues. Part II is entitled "Theoretical Analysis of Straight Knees" and Part III will include the discussion of test results, conclusions and acknowledgments.

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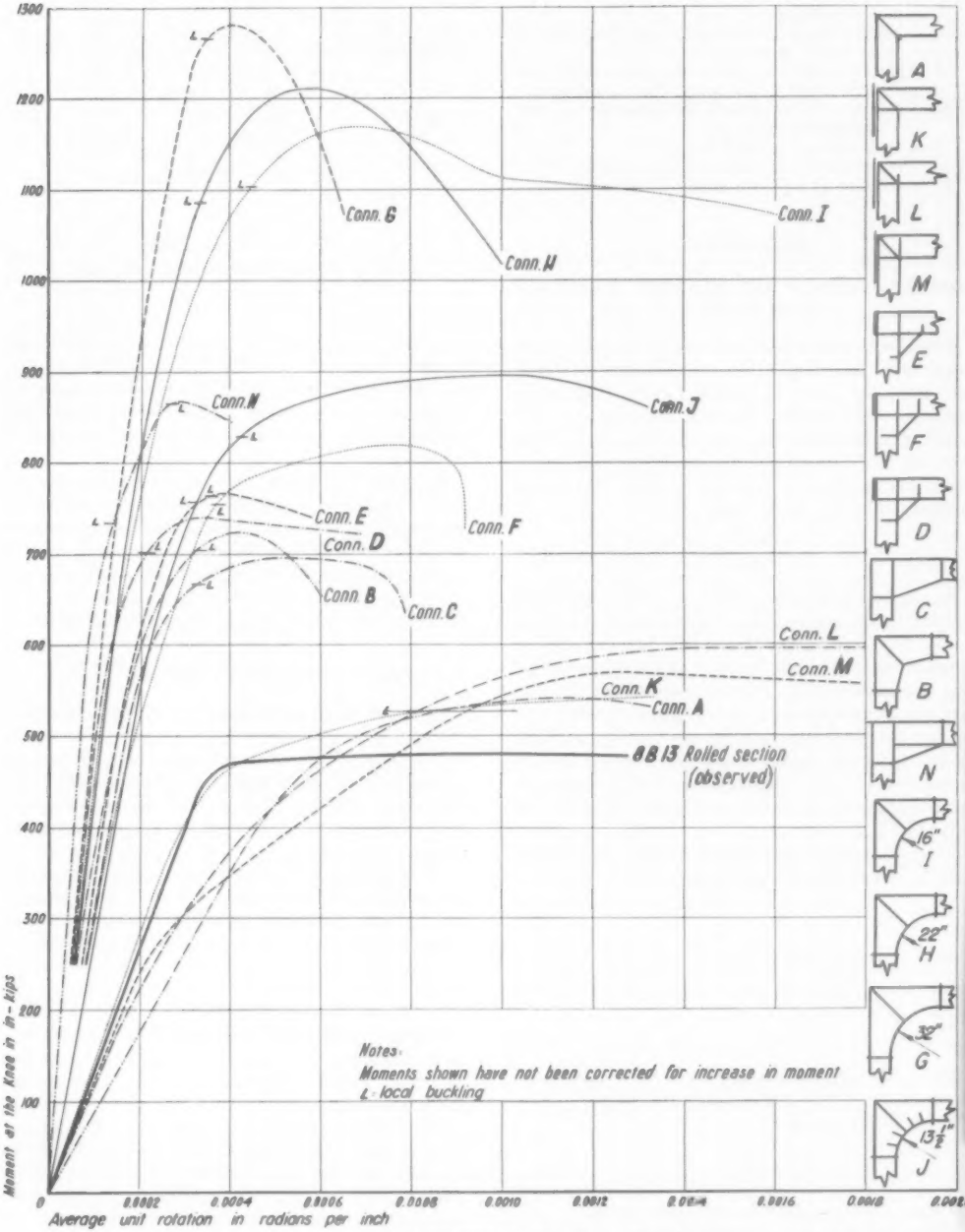

Fig. 52 Connection behavior compared with 8B13 rolled section. (Based on moment at the knee)

NOMENCLATURE

d = depth of section.
E = Young's modulus.
f = shape factor.
I = moment of inertia.
L = length of beam span.
M_p = plastic hinge moment; the ultimate moment that may be sustained at a cross section (according to the simple plastic theory).
M_y = moment at which the flexural yield-point stress is reached.

P_p = load at collapse.
P_y = load at which the yield-point stress is reached.
S = beam section modulus.
Z = plastic modulus; the static moment of the entire cross section about its neutral axis.
ϕ_y = rotation per unit length when the moment just reaches the value M_p.
ϕ = angle change per unit length.
σ_y = lower yield-point stress of the material.
θ_A = rotation at a plastic hinge.

Appendix A

SOME CONCEPTS OF PLASTIC ANALYSIS AND DESIGN

Consider a fixed-ended beam loaded at the third-points as shown in Fig. 5 (*a*). As the load is increased, the yield-point stress, σ_y, will first be reached at the supports. The bending moment diagram for this condition is given by the dashed line in Fig. 5 (*b*). Plotting diagrammatically the load-deflection curve, Fig. 5 (*c*), the load will have reached P_y. This is the limit or full load in elastic analysis.

$$P_y = \frac{9M_y}{2L} = \frac{9\sigma_y S}{2L} \qquad (1)$$

As the load is increased above P_y, plastic zones will develop at the ends until a "plastic hinge" has been formed at the moment value of M_p, the cross section approaching the condition of complete plasticity.* The end moment, M_p, remains constant as the load increases; subsequently the moment at the beam center reaches the yield moment, M_y, and finally a plastic hinge, M_p, is also formed there. The beam is now no longer able to resist additional load and the structure deforms continuously as indicated in the load-deflection curve of Fig. 5 (*c*).†

From the moment diagram at collapse, the ultimate load P_p, is determined from the expression

$$P_p = \frac{6M_p}{L} \qquad (2)$$

The plastic hinge moment, M_p, is a function of the geometry of the cross section and the yield-point stress. It is determined from

$$M_p = \sigma_y Z \qquad (3)$$

where Z, the plastic modulus, is the static moment of the entire cross section about its neutral axis.

Then, from equations 1 and 2,

$$\frac{P_p}{P_y} = \frac{4M_p}{3M_y} = \frac{4f}{3} \qquad (4)$$

the term, f, being defined as the shape factor.
Assuming an average value for WF shapes of 1.125,

$$P_p = 1.5P_y \qquad (5)$$

The simplicity of plastic design methods is apparent: the loads expected on the structure are multiplied by the load factor (safety factor) and the products are termed the "limit" or "full" loads. Following this, M_p may be determined from an expression similar to Equation 2, and a member is then selected whose plastic modulus, Z, is at least as great as that determined from Equation 3.

For portal frames a number of failure modes are possible. Figures 53 (*a*) and 53 (*b*) show two possibilities, the precise mode depending on (1) the ratio of vertical to horizontal load, (2) the ratio of column height to beam span and (3) the relative size of beam and columns. The behavior indicated in Fig. 53 (*c*) is theoretically possible only if side sway is prevented.

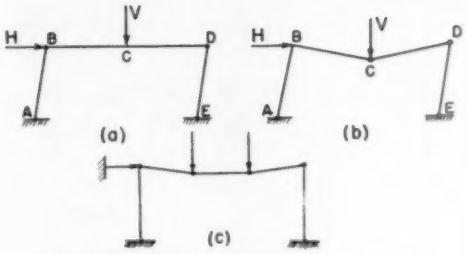

Fig. 53 Modes of failure for portal frames

Portal Frames with Straight Knees

In the case of portal frames the beam transmits moment to the column through a knee. Thus a first requirement of the plastic design method, one of strength, is that *the knee be capable of transmitting the full plastic moment, M_p.* In the case of dissimilar sections the plastic moment of the lighter section will govern.

The usual methods for computing frame deflections are based on the assumption that the connections are rigid. What is actually meant, in the case of square knees, constitutes the second requirement: *the connection must be as stiff as an equivalent length of the rolled sections joined.* This may be seen by reference to Fig. 54. Computations for distribution of moment and for deflection in this frame are based on a complete moment diagram plotted on a horizontal line. Thus the equivalent length of the knee is $AB + BC = AC$ for the extended diagram.

The analysis neglects the fact that the flexural stresses must be transmitted from the beam flanges to the knee web and thence transferred into the column flanges. (Due account may be taken in analysis of the change in moment distribution due to axial load.)

There is negligible advantage in supplying additional stiffness over that of the rolled section, since inelastic rotation will merely occur adjacent to such a connection. However, a knee without sufficient rigidity will allow larger deformations than assumed or calculated elsewhere in the structure.

The above examination of plastic methods also

* This condition is described in Progress Report No. 1.[4]
† The curve is drawn on the basis of simple plastic theory which neglects train hardening.

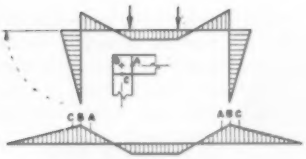

Figure 54

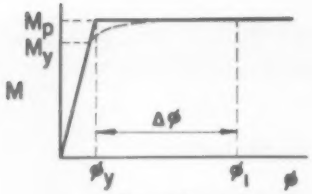

Figure 55

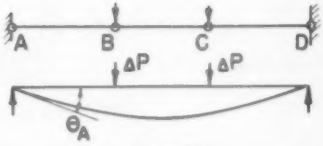

Figure 56

implies that, once the plastic hinge has been formed, further rotation occurs under constant moment, M_p. It is necessary then, to establish a minimum requirement for this "rotation capacity," the least total unit rotation necessary to allow all possible plastic hinges to form in a given frame. This problem will now be examined.

If the ends of the beam in a frame were rigidly attached to very stiff columns, the end restraint would approach that of the fixed-ended beam shown in Fig. 5. The connections of the beam at the fixed ends will be called upon to sustain the moment, M_p, through an angle change sufficient to allow the structure to develop a third plastic hinge at the beam center. Under this condition the beam will support the load P_p as determined from Equation 2. On the other hand, if the beam at its connection to the support will not sustain this angle change at constant moment (due to local buckling, for example) then it will not support a load equal to P_p.

Assume that the load-deflection diagram is as shown in Fig. 5 (*c*), but that the additional rotation at the ends of the beam (required to produce the third hinge) occurs under constant moment, M_p, as indicated by the solid line in the M-ϕ diagram of Fig. 55. In this figure, ϕ is the average unit angle change or the angle change per unit of length. (In the elastic range, $\phi = M/EI$.)

Also assume that there is no strain hardening. The additional rotation, θ_A, of the plastic hinges at A and D (Fig. 56) is equal to that of a simply supported beam due to the load, ΔP, where

$$\Delta P = P_p - P_y$$

Substituting for P_p the value given by Equation 5,

$$\Delta P = 1.5P_y - P_y = 0.5P_y$$

and thus

$$\Delta P = \frac{P_p}{3} \tag{6}$$

It should be remembered that Equation 5 was derived assuming an average shape factor of 1.125. If the shape factor is less than this amount then ΔP is less than $P_p/3$; if the shape factor is more than 1.125, ΔP is greater than $P_p/3$.

The additional rotation at A and D is given as

$$\theta_A = \frac{\Delta P L^2}{9EI} \tag{7}$$

According to the simple plastic theory, it would be assumed that all of this subsequent plastic rotation took place over a very short length, ΔL. The total rotation, θ, that would be measured for this increment of length, ΔL, is made up of an elastic part and a plastic part,

$$\theta = \phi_y \Delta L + \theta_A \tag{8}$$

If now, both sides of Equation 8 are divided by ΔL,

$$\phi_1 = \phi_y + \Delta\phi \tag{9}$$

in which

$\phi_1 = \dfrac{\theta}{\Delta L}$ = total average unit rotation over the length ΔL,

$$\Delta\phi = \frac{\theta_A}{\Delta L} \tag{10}$$

ϕ_y, ϕ_1 and $\Delta\phi$ have been indicated in Fig. 55.

It is evident from expression 10 that the magnitude of ϕ_1 is sensitive to changes in ΔL. When ΔL becomes small then the average unit angle change, ϕ, becomes large. If the length over which the plastic deformation occurs becomes large, then the average unit angle change that must be developed at the support becomes small.

If strain hardening is neglected, then the length of the plastic zone along the beam is proportional to the difference between M_p and M_y (Fig. 55). For the assumed conditions of end restraint, and assuming further, a beam of 8 in. depth and 20 ft. length, the point of inflection is about 54 in. from the knee toward the load point (Fig. 54). The theoretical length of the plastic zone will be about 6 in. For purpose of argument, it will be assumed to be equal to the section depth, d (8 in).

Now in a straight connection with identical members, the length AC is equal to the section depth, d (Fig. 54). If only the connection deforms plastically when the moment reaches M_p, then the length ΔL is equal to d. (Of course if adequate material is placed within the knee area it will not yield, and the additional plastic rotation must occur outside the knee in the rolled beam.)

Substituting the value, d, in the expression for $\Delta\phi$, Equation 10, and using equations 6 and 7,

$$\Delta\phi = \theta_A/d = \frac{\Delta P L^2}{9EId} = \frac{P_p L^2}{27EId}$$

Substituting the value for P_p obtained from Equation 2

$$\Delta\phi = \frac{M_p}{EI}\,\frac{L}{4.5l}$$

Since

$$\phi = \frac{M}{EI}$$

then from Fig. 55,

$$\phi_y = \frac{M_p}{EI}$$

and, finally,

$$\Delta\phi = \phi_y \frac{L}{4.5d} \qquad (11)$$

for the case of a fixed-ended beam with third-point loading.

Using as an example, the L/d proportion of the 8-in. beam on a 20-ft. span,

$$\Delta\phi = 6.7\phi_y$$

and from Equation 9

$$\phi_1 = 7.7\phi_y$$

For any other loading, the required value of ϕ_1 may be determined.

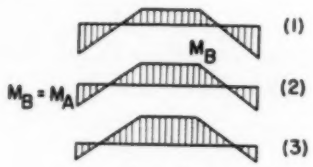

Figure 57

Depending on the proportions of the frame, the beam will have varying end restraints as indicated in Fig. 57. The upper limit of restraint is the fully fixed condition shown in (*1*), and the lower limit (zero end moment) is approached by (*3*). Cases (*2*) and (*3*) are examples in which no rotation-capacity of the knee is required beyond that to develop the plastic hinge, since the first plastic hinge will develop at the center of the beam.

Frames with Haunched Knees

Assuming that a built-up connection is desirable for reasons of economy it is not clear that plastic design is suited to the case of haunched knees. Haunches are the product of one of the basic principles of elastic design; that is to say, the section depth of the haunch is increased where the expected bending moments are increasing. Thus there would appear to be no advantage in the development of plastic hinges, since, for an "ideal" design, the whole structure would become plastic at approximately the same load.

Discussion by H. H. Bleich*

Having had the opportunity to see Professor Topractsoglou's extensive and interesting paper, the discusser desires to emphasize the importance of one of the conclusions drawn by the author concerning connections of the type *P*.

Connections of this type are cheap to fabricate and have been used quite frequently. While the more theoretically inclined stress analysts are fully aware of the high shear stresses in the web of the knee, it seems that many designers do not fully realize this fact. It is therefore of considerable interest that the tests demonstrate beyond any doubt that these high shear stresses really occur and that the knee will show large deformations when the web in the knee reaches the yield point.

Consider Fig. 19, which shows the rotation curve for the 14WF beam, the 8WF column and the knee. If the bending stresses alone would control, the knee should yield at the same moment as the weaker of its two members, that is, at $M = 1050$ in.-kips. Actually, yielding was observed at $M = 570$ in.-kips. In this case the weakness of the web in the knee reduced the bending strength by nearly one-half! It is only too obvious that this important result *must* be considered in actual design.

It is a challenge to the designers to find a simple and cheap, yet effective, way to reinforce the web of the knee such that it can carry the same moment as the column or beam. Such strengthening of the knee is necessary for an economical over-all design.

* Assoc. Prof. of Civil Engineering, Columbia University, October 1950.

Pressure Vessel Heads Under Internal Pressure

The paper "Pressure Vessel Heads Under Internal Pressure (Elastic Stresses and Deformations in Axially Symmetrical Shells)—Part I. General Considerations," by W. R. Burrows, Chairman, Design Div., Pressure Vessel Research Committee; Assistant Chief Engineer, Whiting Refinery, Standard Oil Co. (Indiana), covers the development of engineering-type formulas for elastic stresses and deformations in heads and shells of vessels under internal pressure.

The classical theory is introduced by sketching its gradual development historically. A size limitation is placed on its use. Shells with D/T ratios less than 30 are excluded. As a result of the PVRC Design Division's work as a whole, its experimentations, calculations, analysis and discussions, a form of the Geckeler solution is proposed as a basis for formulas for engineers to employ as a supplement for graphical and tabular results obtained by more accurate methods. General formulas and procedures suitable for the application of this Geckeler type approximation to specific studies are given. The discussion is in sufficient detail to be useful to students of the problem as well as to engineers.

Limited copies of this paper are available by writing to the Secretary, Pressure Vessel Research Committee, 29 W. 39th St., New York 18, N. Y.

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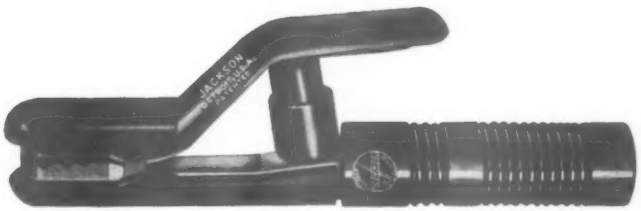

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